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SURFACE DANGER ZONE (SDZ) METHODOLOGY STUDY, PROBABILITY BASED SURFACE DANGER ZONES

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13. ABSTRACT (Maximum 200 words)

Surface danger zones (SDZs) are exclusion areas identified to protect personnel from weapons firing during training. Limited real estate at certain training sites and observation of inadequacies in current danger zones has forced the Army to investigate alternative methods of developing SDZs. One alternative is the development of probability based SDZs. This report addresses that alternative. A theoretical probability model was developed to evaluate the various parameters contributing to the SDZ definition. Specific emphasis was placed on the effects of ricochet because of its complexity and the significant affect ricochet has on the shape and size of the SDZ. Ricochet, in combination with aimer/system error, provides the necessary parameters to produce probability based SDZs for direct fire weapons. For indirect fire weapons, the additional affects of fragmentation are included. This study also discusses a computer simulation program developed to implement this model. The application of this program is exemplified by sample SDZs for .50-caliber machine gun and 9-mm pistol under a unique set of conditions.

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INTRODUCTION

Present methodology for developing and constructing surface danger zones (SDZs) is based on the philosophy of total confinement of hazardous fragments. The intent is to define an area that is unsafe within its boundaries and safe outside those boundaries. Typically, one SDZ is described for a particular weapon ammunition combination and its application has no reservations. Although these zones are expected to offer "total safety," their construction/development is based on limited data; they are tailored for ease of drawing and some of the mandatory safety factors were added arbitrarily. Visual observations of firings as well as test data do not support the philosophy of existing SDZs. The adequacy of these zones was challenged by the field. They have specifically expressed concerns with the impact of the SDZs on real estate and have expressed a need to produce SDZs with a quantifiable risk (ref 1). These issues resulted in the decision to conduct this study.

This report deals with a specific technique for developing probability based SDZs. It identifies the parameters contributing to a probability based SDZ and the method of developing the data necessary to describe these parameters. This report begins by describing the philosophies and procedures currently used in developing SDZs and discusses their shortcomings. It describes the data required and how this data is currently acquired. This is followed by a discussion of the approach, the assumptions, the parameters considered, and the data required to quantify the risk level. A discussion on the theoretical model is provided which defines probabilistic SDZs, necessary data analysis techniques, their application, and the theoretical probability techniques that are applicable to creating probability density functions. Separate probability models are presented for each of the following cases: dealing with the direct fire mode, nonexplosive projectile; dealing with the direct fire mode, explosive projectiles or indirect fire mode at low quadrant elevation; and dealing with the indirect fire mode. A practical application of the theoretical model is discussed and sample SDZs are presented for the .50-caliber machine gun and 9-mm pistol.

BACKGROUND

The present requirements for developing and constructing SDZs for conventional ammunition are detailed in DARCOMR 385-24 (ref 2) and AR 385-63 (ref 3). DARCOMR 385-24 specifies the data required and AR 385-63 outlines the construction of SDZs based on this data. The SDZs produced in the past and documented in AR 385-63 have strived to define a danger zone that will contain all hazardous fragments within its boundaries, the implication being that outside these boundaries it is safe.

These danger zones have followed one pattern: a pie-shaped contour with segmented areas to control different types of hazards. The pie shape contours are applicable for both the direct fire mode and the indirect fire mode. The only difference is the procedures used to achieve this shape. Sample SDZ diagrams for the direct fire mode and the indirect fire mode presently used and prescribed in AR 385-63 are shown in figures 1 and 2. It should be noted that although these diagrams are typical of SDZ diagrams in use, they are subject to tailoring based on the technical data observed. In recent years there has been a considerable change to the shape of the direct fire danger zones because of field concerns with the ricochet danger. This concern was substantiated by ricochet test data. An example of one of these fans that was influenced by the effects of ricochet is shown in figure 3.

In constructing SDZs there are several technical elements that are taken into consideration; these include the following:

- Range at various elevations and weight of propelling charges
- Dispersion
- Ricochet
- Ordinates at various elevation and weights of propelling charges
- Fragmentation
- Muzzle debris
- Rearward debris
- Overpressure/noise

The effects of all these elements are combined to trace out an area that is defined as unsafe within its boundaries and safe outside these boundaries.

The data for these elements is generated during system development, primarily during technical testing, by the Test and Evaluation Command (TECOM). In addition to the data acquired through testing, there are safety factors applied to define danger areas within the SDZ. The safety factors are specified in AR 385-63.

Data Development

Surface danger zone data is developed through a variety of tests which are not designed solely for that purpose. Test operating procedure (TOP) 3-2-607 (ref 4) provides guidance for acquiring the data necessary to establish danger zones for

training, target practice, and combat when using conventional weapons and ammunition, small rockets, and guided missiles. This TOP provides a standardized method of presenting data. The actual procedures for obtaining the required data are described in other TOPs, which are referenced in this TOP. The scope of the test program is designed to address the elements previously mentioned as necessary for constructing SDZs. The specific tests called out in this document are discussed next.

Firing tables are created by the Firing Tables Branch at the Armament Research, Development and Engineering Center (ARDEC) using test results obtained through testing in accordance with TOP 3-2-601 (ref 5). These tables, although developed primarily to assist in firing performance and accuracy, are used to establish safety limits for range and altitude. The ballistic information collected during these tests are also useful in calculating projectile trajectory after ricochet. For the indirect fire mode, the firing tables also provide probable errors for both range and deflection which are used to define the probable impact area about the target.

Ricochet testing and analysis is conducted in accordance with TOP 4-2-814 (ref 6). This TOP outlines procedures for conducting ricochet tests and for analyzing data. Results of this procedure are ricochet equations for different impact media. These equations along with ballistic coefficient, muzzle velocity, target ranges, elevation angles, drag coefficient before impact, and form factors after impact are input variables to the ricochet computer program. This computer program calculates range and deflection of first and subsequent impacts until the ricochet velocity or ricochet elevation angle is less than or equal to zero. Results are then plotted out for various preselected form factors. Since there is no test data measured to assess flight information after ricochet, selection of a drag form factor is arbitrary. In order to maintain conservatism without being unrealistic, form factor 2 (which is equivalent to twice the drag coefficient of the projectile before ricochet) is used for ricochet calculations irrespective of impact angle. This form factor value is used predominantly for small to medium caliber ammunition. A slightly higher form factor is used for tank ammunition. The ricochet danger areas produced using this analysis technique have had a significant impact in real estate requirements and have resulted in changing the shape of the conventional danger zones. For years the ricochet danger area followed a pie shape and was represented with a 5-degree angle for small caliber items and a 10-degree angle for tank systems. Today the ricochet danger area reflects a "bat wing" profile (fig. 3). This is an interim measure until a more comprehensive methodology is developed and officially approved.

The arena test as per TOP 4-2-813 (ref 7) provides the necessary information to assess hazards due to fragments from an explosive projectile, and therefore helps to define the fragment danger area.

Noise levels at crew positions and the determination of the 140 dB contour is derived using test procedures in TOP 1-2-608 (ref 8).

Photographic coverage in accordance with TOP 4-2-501 (ref 9) and retrieval of discarded parts, as per TOP 4-2-816 (ref 10), are used to evaluate muzzle debris or discarded parts further downrange.

TOP 3-2-607, Appendix A, outlines the test procedures for evaluating the effects of rearward debris from recoilless rifles, small rockets, and guided missiles.

Besides the technical data created during development and testing, there are safety factors/restrictions that are specified in AR 385-63 that are used in constructing a final SDZ. These factors include requirements such as a 5-deg angle about the firing line to account for dispersion; construction of SDZs for tank gunnery with the maximum range set for a 10-deg gun elevation and limiting elevation during firing to a 5-deg elevation, and defining the impact area for indirect fire to be 8 probable errors (PE) to the right, left, and behind the target, and 12 PE in front of the target.

The combination of the technical data derived through testing and the safety factors specified in AR 385-63 are used by the development community to construct a recommended SDZ which is then transmitted to HQ, Training and Doctrine Command (TRADOC) for their review and approval. TRADOC may alter these zones to allow for easy drawing or to fit any particular field firing conditions. The final SDZ is published by TRADOC and disseminated to the field for use.

Shortcomings

Observations during training and testing have revealed several shortcomings with the present methodology of defining SDZs. These shortcomings are with both the data and the methods of constructing the SDZs. They are significant enough to raise serious questions about the adequacy of our present SDZ.

As mentioned earlier, the creation of our present danger zones is based on the combination of technical data and safety factors. The technical data has not always been readily available. An example of this is firing table data for small arms and direct fire weapons. There is no specific requirement for generating firing tables for certain small arms; however, this information is critical to establish maximum range. In addition, firing generated for direct fire weapons does not account for meteorological factors such as wind, air density, and temperature. The values generated are only for ambient temperature and sea level conditions. Meteorological affects are known to introduce significant differences in flight characteristics and will significantly affect the maximum range. These variations, although not considered in the past, are now taken into consideration and specific correction factors are available to the field for use.

Fragmentation hazards, which play a major role in defining a danger zone for an explosive projectile, are normally determined based on the fragmentation dispersion of one to three rounds. This sample size is not a statistically valid representation of population distribution of fragments for a particular ammunition. Proposals were put forth to modify the test procedure to increase the sample size to five. This will give better representation of fragment distribution, but the sample size is still small when considering statistical significance and confidence. Another concern is that there has not been a consistent way of defining this area because of the multitude of criteria for what constitutes a hazardous fragment. Comparisons of the different criteria that are available are given in figure 4. In addition to these criteria, there are cases where assumptions are made that any fragment is considered hazardous.

For many years ricochet hazards were handled by designating a specific sector in the danger zone which was either 5 deg, 10 deg, or 13 deg depending on the caliber of the munitions. These angles are not based on any established test data. Testing in the last 10 years clearly demonstrates that these danger areas are not sufficient to adequately control hazards due to ricochet. They are especially deficient at short range. Although ricochet testing was conducted for some munitions there is a large number of munitions for which ricochet testing has not been completed.

Ricochet testing is critical to defining hazards associated with ricochet, provided that the test procedures are adequate to obtain all the necessary data. This aspect has been a major drawback in the present ricochet testing. The drawbacks are in procedures, instrumentation, and the large cost involved to conduct such tests. These factors have had a significant impact on the quality of data gathered. Sample size has been small; not all the parameters were measured, and not all possible ricochet angles were tested. Because of the limitations in the test data, the computer simulation used to predict ricochet danger areas is incapable of providing a good estimate. There was a tendency to overstate the problem and present a conservative danger zone, which has demanded an increase in real estate required for these danger zones.

Aside from the shortcomings associated with the technical data, there are also shortcomings related to the safety factors required by AR 385-63. These factors were arbitrarily set because of the lack of accurate data. One such factor is the 5 deg dispersion requirement for all direct fire weapons. This is required whether it's a small arms danger zone or one for a tank gun. Assuming that this angle for dispersion may be adequate for small arms, it appears to be overly conservative for tanks. Another such factor is that the eight PE in range and deflection specified for indirect fire weapons does not fully assess the system errors. The PE used are those derived from the firing tables and only take into consideration errors such as those associated with air density, spin drift, and meteorological conditions. No account is taken of aimer error although it plays such a prominent part in direct fire weapon SDZ. In addition to these obvious contradictions, the safety factors are applied religiously for all ammuni-

tion irrespective of the type, construction, frequency of use factor, or training facility. This aspect in itself suggests that either these factors are conservative enough to fit all cases or are not properly applied. In summary, the arbitrary nature of these safety factors, along with their effectiveness as control measures, are suspect and need to be better assessed. This requires a combination of testing and analysis.

METHODOLOGY FOR PROBABILITY BASED SDZs

General

The objective of this study was to produce a methodology that provides detailed procedures that can be used to gather or locate the necessary data, perform statistical analysis on the pertinent data, and produce SDZ contours for various levels of probability. To accomplish this, a three-part program was established. The first part was defining all parameters which may effect the SDZ and identifying the data necessary to properly measure these parameters. The second part involved the development of a theoretical probability model capable of addressing all of these variables and predicting the eventual resting place of any projectile. The third part was to develop a computer program capable of implementing the theoretical model and identifying the data required for input into the model/computer program.

Parameters

There are several parameters that are necessary to properly define the danger zone for a particular weapon-ammunition combination. Some of these parameters are independent, but most are dependent, and actually are inputs defining other parameters. For example, flight dynamics not only define the ballistic capabilities of a projectile, but also are necessary to trace ricochet patterns. The following parameters are the key to defining danger zones: flight dynamics, system/aimer error, ricochet, and fragmentation. The following paragraphs will discuss the importance of each in the danger zone determination and explain how this information is gathered and where it is available.

Flight Dynamics

Flight dynamics data provides the necessary ballistic information to calculate the flight pattern of a particular projectile before and after ricochet. This data is normally developed during technical testing and reduced to proper format by the Firing Tables Branch, ARDEC. Test procedures for collecting this data are defined in TOP 3-2-601, and the Firing Tables Branch has the necessary computer programs and data reduction capability to properly reduce this test data.

System/Aimer Error

System/aimer error defines the dispersion about the line of fire both laterally and vertically, and it is influenced by the weapon, ammunition, and shooter aiming error. This provides the necessary information to define a hit probability density function about the center of the target or a point on the ground. The significance of this information is that it establishes the point from where ricochet contours are determined. A report on aimer error (ref 11) discusses the contributing factors to system/aimer error for small arms, tank gunnery, and artillery. It also provides system/aimer error data for these weapons. The data is presented as population standard deviation on the horizontal and vertical planes with respect to target range. This data is given for both single-shot mode and burst-firing mode. In this format this data can be easily used to define the hit probability about the center of the target or a point on the ground.

Ricochet

Ricochet data provides the necessary information to define the ultimate resting place of a projectile after it has struck a given object. The composition of these objects may vary significantly, ranging from hard substances such as steel to softer substances such as water. The ricochet substance is normally referred to as ricochet media and its composition will have significant impact on the ricochet variables after impact. In addition to the ricochet media, the impact angle with this media will also affect the ricochet behavior. The ricochet variables that are of interest are those that will allow calculating the projectile trajectory after ricochet. These include ricochet velocity, ricochet angles (azimuth and elevation), and drag coefficient after ricochet. As these are directly dependent on the impact angle, they are measured with respect to that angle. Ricochet testing and analysis is further discussed in later sections of this report.

Fragmentation

Fragmentation data provides the necessary information to define an exclusion area around explosive projectiles to protect from the effects of the ammunition fragmentation. There are two aspects to consider when dealing with fragmentation, one involves test procedures and data analysis and the other involves definition of a hazardous fragment. Test procedure and data analysis are well described in TOP 4-2-813. This procedure has been used for many years and is considered adequate for evaluating fragmentation affects; the one drawback is the small sample size normally used.

Hazardous fragments can be defined in several ways. The differences between the criteria are shown graphically in figure 4. The three criteria most widely used are the 58 ft-lb criteria used in establishing fragmentation hazard distance for explosive hazard classification; the Joint Munitions Effectiveness Manual (JMEM) criteria used for evaluating munition effectiveness but also used for safety considerations; and the Chemical Systems Laboratory (CSL) criteria used by ARDEC to evaluate hazardous effects of fragments. As can be seen from the graphs, there is significant differences between the three criteria for smaller size fragments while they converge for the larger size fragments. The JMEM criteria is the more conservative of the three and is used in the computer program developed for this study.

Probability Model

The theoretical probability model for SDZ risk definition was developed by Dr. Hans Levenbach (ref 12) for Army use. The basic hypotheses of the model for constructing probability based SDZ is to assume the firer is aiming and firing at the target. With this basic assumption in mind, it is possible to study the various factors that influence the bullet trajectory and project where that bullet could potentially strike. System/aimer error (one of the variables in the model) defines potential hits about the target or a point projected on the ground. After striking the ground/target, the round will either explode and fragment, bury itself into the ground, or ricochet. Because the geometric configuration of the impact surface cannot be realistically modelled, it is assumed that the impact surface could present all possible angles of impact with equal likelihood. This is considered to be a conservative representation to account for the vast variety of conditions that may be encountered in the field.

The probability model does not consider situations that are outside the normal variance of the parameters such as accidentally firing a weapon at an angle that may send the projectile to its maximum range. This situation is similar to that of firing a weapon 45 deg to the right or the left of a target and is not a normal deviation which can be quantified. These types of conditions can be classified as rare to improbable occurrences. The probability model only deals with normal events and the measurable variations about these normal expectations or behaviors.

The model was designed to consider four different cases. These four cases adequately represent the different firing modes, the potential hazardous conditions associated with these firings modes, and the particular munitions that may be used.

Case 1

This case considers a nonexplosive projectile in the direct fire mode. This projectile hits a point on the target/ground and it either remains there, breaks up, or it will ricochet upon impact and continue its flight (fig. 5).

Case 2

This case considers an explosive projectile in the direct fire mode. The projectile impacts a point on the target/ground and it either explodes where fragmentation affects must be considered, or fails to function and ricochets to a certain distance, where there is a potential repeat of the initial impact options (fig. 6).

Case 3

In this case, it is assumed that the projectile (explosive or nonexplosive) is fired at a sufficiently high quadrant elevation so that there is no ricochet. Total system error presented in PE and fragmentation are the only significant factors (fig. 7).

Case 4

This case considers an explosive projectile fired in the indirect fire mode with a low quadrant elevation such that ricochet may occur if the projectile does not function on impact. This is similar to case 2 (fig. 6).

The total SDZ probability for each case is presented as follows:

Case 1: $$P_T = (P_{se})\,(P_r)\,(P_{ia})\,(P_{R/r}) \tag{1}$$

Case 2 and 4: $$P_T = P_{se}\,[P_f + (1-P_f)\,(P_r)\,(P_{ia})\,(P_{R/r})] \tag{2}$$

Case 3: $$P_T = (P_{se})\,(P_f) \tag{3}$$

where

P_T = Total SDZ probability

P_{se} = Probability due to system/aimer error

P_r = Probability of ricochet

P_{ia} = Probability of striking the surface at a specific impact angle

P_f = Probability of an explosive projectile function

$P_{R/r}$ = Probability of a particular ricochet trajectory

Although all these variables play an important role in the final SDZ probability definition, the affects due to ricochet are most significant and extremely complex to model. Dr. Levenbach's study concentrated on the analysis of ricochet and on developing procedures for deriving a probability distribution function that would describe the probability contours due to ricochet, $P_{R/r}$. Given that ricochet has occurred, there are four variables that are necessary for calculating the ballistic equations for the ricochet condition. These include: ricochet velocity (V_r), ricochet elevation angle (e_r), ricochet azimuth angle (α_r), and drag form factor. Three of these variables (V_r, e_r, and α_r) are treated probabilistically and establish the initial conditions, for a specific probability level, needed to calculate projectile trajectory after ricochet. The drag form factor is treated deterministically and is related to the total angle of turn (the degree of angular turn the projectiles incoming vector makes with its outgoing or ricochet vector) β

where

$$\beta = \cos^{-1}\{\cos(\alpha_r)\cos(e_r)\cos(i) - \sin(e_r)\sin(i)\} \qquad (4)$$

and

α_r = ricochet azimuth

e_r = ricochet elevation

i = impact angle

The ricochet diagram at figure 8 helps illustrate this relationship.

The probabilistic approach treats the three variables (V_r/V_i, e_r, and α_r) as dependent variables. The physical range limitation of these variables is as follows

$$0 \leq V_r/V_i \leq 1.0 \qquad (5)$$

$$-90 \text{ deg} \leq \alpha_r \leq 90 \text{ deg} \qquad (6)$$

$$0 \text{ deg} \leq e_r \leq 90 \text{ deg} \qquad (7)$$

Because of the physical limitations in the range of variations, these variables cannot be assumed to have a joint trivariate normal distribution. Therefore, to define a workable joint probability distribution, it became necessary to redefine the variables. This was accomplished by transforming the variables through the application of a single mathematical function to all the variables. Transformation is done using logic transform, and the transformed variables are as follows:

$$(V_r/V_i)_t = 1n\ (V_r/V_i) - 1n\ (1-V_r)/V_i) \quad (8)$$

$$\alpha_t = \tan\ (\alpha_r * \pi/180\ \text{deg}) \quad (9)$$

$$e_t = 1n\ (e_r) - 1n\ (90\ \text{deg} - e_r) \quad (10)$$

These transformed values can be assumed to have a trivariate normal distribution. The application of this relationship in producing probability contours due to ricochet are discussed in reference 13.

RICOCHET TEST AND ANALYSIS

Ricôchet plays a very significant role in defining the SDZ contours, and its unpredictability poses some serious difficulties in properly assessing its full impact on the danger zone. There are several factors that influence the behavior of a projectile after it ricochets. These include the impact angle, ricochet media, and bullet construction to just name a few. There are other elements which are suspect (i.e., spin rate) and probably some that we are not aware of. Designing a test program that properly addresses the variety of the influencing factors and obtaining the necessary data is a considerable undertaking. In view of the difficulties and the enormous cost associated with such an undertaking, it was necessary to bound the problem within reasonable expectations. Also, considering that part of the aim of this study was to define a test methodology for ricochet, it was easier to narrow this effort to that aim and exclude ricochet influencing factors that would not impact on the test methodology. For example, although the impact media has a significant affect on ricochet it was not necessary to test against a variety of impact media to develop a test methodology. The methods used to test for an impact media consisting of sand would be equally appropriate for testing for earth, steel, or concrete.

Ricochet testing was done in the past for a small variety of ammunition and impact media. TOP 4-2-814 established by TECOM was used for a number of these tests; however, there have been several problems which include: small sample sizes,

not enough impact angles tested, and no measurements made to ascertain drag coefficient after ricochet. These problems did not occur through ignorance, but were influenced by some serious and real factors. Sample size, for example, is directly related to cost, and since ricochet testing is quite expensive, one way to limit this expense is to reduce the sample size tested. The cost of doing ricochet testing is not directly related to the cost of the item. It is predominately a factor of test time. In the case of large caliber ammunition, the cost is influenced by both item cost and test time. In addition to cost, the other factor was the underlying philosophy for developing SDZ. The current philosophy is to try to define a danger zone that offers optimum safety. So, with this aim, calculations and assumptions were made to insure that errors were on the safe side. For example, the drag form factor was originally taken to be one for projectiles after ricochet (ref 14). This assumes that the projectile continues to fly with the same level of stability after ricochet as it did before ricochet. This, of course, is a very conservative assumption. Without any drag data, there is no other assumption that can be confidently made, and since it did not compromise safety, there was no strong reason to attempt such measurements. Also, it needs to be noted that the technology then, and in most cases even now, does not allow making these measurements with a high degree of consistency and confidence. Another significant philosophical difference between the current methodology and what is being proposed in this report is that the present analysis is based on a deterministic approach as opposed to a probabilistic, which significantly influences the data requirements. The data collected presently could not be used for probabilistic modelling.

Recognizing these shortcomings, it was decided that a comprehensive ricochet test program was needed to establish new and improved procedures for conducting ricochet testing. This effort included defining the test setup, the parameters to be measured, and the type of instrumentation to use. It also included actual testing of several bullets to allow demonstration of the probability model. Three types of rounds were selected for the ricochet test. These include the .50-caliberiber M33 Ball, M17 Tracer, and the 9-mm M882 Ball round. These rounds are of different caliber and represent different shapes and materials. The M33 Ball is a steel core with a copper jacket while the tracer is lead filled with a copper outer shell. Both rounds have a pointed nose while the 9-mm M882, which is lead core with a copper jacket, is blunt nosed. All these factors play a role in the ricochet results and these bullets offer enough diversity to make them good candidates to see how these variations may actually affect the ricochet results.

Selection of ricochet media was largely influenced by ricochet studies conducted by the Ordnance Board in the United Kingdom (UK). Observations made from firings into hard surfaces, such as steel, and soft surfaces (earth, sand, gravel, and turf) indicate a difference in ricochet behavior between hard surfaces and soft surfaces, but no significant difference between the media classified under soft surfaces. As a result the Ordnance Board designed their test program to fire on damp sand and armor plate. Damp sand was chosen to be representative of soft surfaces and armor plate was

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Recognizing these shortcomings, it was decided that a comprehensive ricochet test program was needed to establish new and improved procedures for conducting ricochet testing. This effort included defining the test setup, the parameters to be measured, and the type of instrumentation to use. It also included actual testing of several bullets to allow demonstration of the probability model. Three types of rounds were selected for the ricochet test. These include the .50-caliberiber M33 Ball, M17 Tracer, and the 9-mm M882 Ball round. These rounds are of different caliber and represent different shapes and materials. The M33 Ball is a steel core with a copper jacket while the tracer is lead filled with a copper outer shell. Both rounds have a pointed nose while the 9-mm M882, which is lead core with a copper jacket, is blunt nosed. All these factors play a role in the ricochet results and these bullets offer enough diversity to make them good candidates to see how these variations may actually affect the ricochet results.

Selection of ricochet media was largely influenced by ricochet studies conducted by the Ordnance Board in the United Kingdom (UK). Observations made from firings into hard surfaces, such as steel, and soft surfaces (earth, sand, gravel, and turf) indicate a difference in ricochet behavior between hard surfaces and soft surfaces, but no significant difference between the media classified under soft surfaces. As a result the Ordnance Board designed their test program to fire on damp sand and armor plate. Damp sand was chosen to be representative of soft surfaces and armor plate was selected to represent hard surfaces. The test program developed as part of this study followed the same logic process and was setup to closely mirror the UK test program.

To produce drag form factor data after ricochet required reducing the Weibel radar measurements. This was done using a specially developed technique (ref 17). Due to the small radar beam angle and the large variations in the dispersion resulting from ricochet, especially at high impact angle, it was not possible to obtain any useable data for impact angles greater than 10 degrees. Therefore, for angles greater than 10 deg, the drag form factor was predicted based on the results from 5 deg and 10 deg ricochet firings. The drag form factor is presented relative to β (figs. 9 through 12). A conservative approach was taken in defining the drag form factor curve versus β. The curve chosen fits the minimum drag form factor points for a particular β.

The probability of ricochet was derived by computing the maximum likelihood estimate for a given confidence level using the test data for the number of rounds that did ricochet relative to the total number of rounds firing per impact angle. The estimated probability of ricochet with respect to the impact angle for .50-caliber when fired into sand is shown in figure 13.

The reduced ricochet data for .50-caliber M33 and 9-mm rounds is presented in tables 1 through 7. Results of simple statistics performed on these variables are depicted in tables 8 through 11. The following is an explanation of the headings in tables 1 through 7.

Round no. -	The number of the rounds fired in the test
Impact angle -	The angle at which the projectile hits the impact media
Vi (m/s) -	Impact velocity in m/s
Vr (m/s) -	Ricochet velocity in m/s
Vr/Vi -	Velocity ration between the ricochet velocity and impact velocity
Azi/E -	Ricochet azimuth angle with respect to earth coordinates
Elev/E -	Ricochet elevation angle with respect to earth coordinates
Azi/R -	Ricochet azimuth angle with respect to ricochet surface
Elev/R -	Ricochet elevation angle with respect to ricochet surface
Beta -	Total angle of turn

APPLICATION OF PROBABILITY MODEL

The application of the probability model is more complicated than just assigning values to the individual probability elements described in equations 1 through 3. Each of the probability elements is affected by the firing range characteristics. These include firing position, target location, and terrain characteristics both from a topographical viewpoint as well as geological. Therefore, it is critical that the firing range characteristics be set before the probability model is applied to produce a danger zone. The importance of these variables will be discussed and illustrated.

Firing position is critical in defining the gun height. The dispersion footprint due to system/aimer error will vary directly proportional with gun height. This influences the probability of ricochet as well as the point where the ricochet trajectory begins, given the ricochet occurs. How gun height affects the trajectory and impact point on the ground is illustrated in figure 12.

Target location similar to gun height will influence the dispersion footprint due to system/aimer error. It should be noted that neither the gun height nor target location affect system/aimer error standard deviation, they only influence how this error is projected on the ground. Similar to the gun height, target locations will influence the probability of ricochet as well a the point where the ricochet trajectory begins, given that ricochet occurs. The affects of target location are illustrated in figure 13.

Terrain characteristics play an important role in many respects. Topographically the firing range may be relatively flat, may contain numerous hills, may be sloped, or it can take on all these characteristics. This influences the initial impact point, ricochet probability and behavior, the ricochet trajectory, and subsequent ricochet. Taking into consideration that the impact point can be any configuration in all types of terrain, it was decided to assume in this model that the impact angle can take on a multitude of values and that the probability of encountering a particular impact angle is uniformly distributed; that is, P_{ia} in equations 1 and 2, is set to equal one. A hemisphere is used to model this condition. The other aspect of terrain that is of interest deals with the ground formation (earth, sand, rock, gravel, etc.). All these media will influence the ricochet behavior in different ways. Some attenuate ricochet behavior while others may amplify it. They will influence the probability of ricochet versus impact angle and the probability ricochet contours. Some aspects of the terrain and its affect on the danger zone determination are illustrated in figure 14.

Recognizing that the previous parameters are key elements in danger zone definition as they influence projectile trajectories prior to and post ricochet and the probability of ricochet, it is imperative that these parameters be set prior to performing the probability calculations. For the purpose of demonstrating the output of the probability methodology model, the following firing range characteristics are used: the target is a silhouette - E type; target location was derived using TC 25-2 (ref 18) and

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SUMMARY

Conventional SDZs strived to produce a danger zone that could contain all hazardous fragments. This required taking into consideration abnormal behaviors and accidental acts that may result in hazardous fragments exiting the danger zone. This required large danger zones and high demands on real estate. In addition, the conventional SDZ was developed on limited data and with arbitrary safety factors added. This is not the case with this methodology. This study provides an alternative to conventional methods of developing SDZs both in technique and assumptions. This study has allowed us to develop the capability to produce future SDZs with specific probability risk levels. The probability based SDZs assume normal behavior with normal variances. It does not consider abnormal or accidental acts that may result in a hazardous fragment exiting the range. These conditions cannot be measured and expected frequencies cannot be assigned.

In addition, the methodology can be used to address specific conditions that may be particular to a training site or a training scenario. This will become very useful where real estate constraints may demand reduced range. It now will be possible to reduce the range and estimate the risk associated with this change. This will provide the decision makers with a quantifiable risk and reduce the level of uncertainty in decision making.

The SDZs produced under this methodology are based on the concept of "range to target." This requires knowledge of the target locations. Given this information, the model estimates probability zones in a three-dimensional mode around these target locations. This could be done for every target or it can be designed to look at the minimum and maximum target engagement distances and calculate danger zones between these two extremes. The three-dimensional capability allows defining danger to flying aircraft near a training site or aircraft that may be involved in the training exercise.

This methodology study has fully met its objective. The ability exists to produce probability based SDZs. The theoretical model and the computer program implementing this model make this possible. What is now required is test data on particular weapon-ammunition systems. This study defines the data needed and how to collect this data. Specific applicable test procedures were identified and described. In addition, this study undertook to improve test procedures that were inadequate or incomplete. One such test method requiring further improvement was that for ricochet. The ricochet test program conducted as part of this study allowed the introduction of several improvements. In addition, there was considerable knowledge gained that will further help improve this test method to where it's more effective and efficient. The ricochet test procedure evaluated under this study deals primarily with small caliber ammunition. A great deal more work is required to improve this test method to the point where it can be used for larger caliber ammunition. A combination of analysis

and testing is needed to upgrade the ricochet test methodology to where it can be used to collect useable data for larger caliber ammunition.

The ricochet testing conducted as part of this test was limited to firing at a soft target represented by armor plate. These are extreme conditions chosen to gain insight as to how significant a role does the impact media play. There is a variety of impact media that can be encountered in the field that will need to be addressed in the future. This will require actual testing of these media to properly evaluate their effects on ricochet. Because of the difficulty of conducting such tests, as well as the expense involved, it is important to explore methods that can be used to predict ricochet behavior for various impact media. The effects of different media on ricochet and how this may be predicted once the model has been fully validated with test data is discussed in reference 20. Instrumentation is another major component of the ricochet test method and requires modification to make the test more effective and efficient. The unpredictability of ricochet makes conventional instrumentation marginally effective. This was especially evident in trying to measure drag coefficient after ricochet.

Drag coefficient after ricochet plays an important role in determining the final resting place of a projectile after ricochet. This information was not gathered in the past, but a drag form factor arbitrarily chosen. The ricochet test conducted for this study employed three radars to measure projectile flight behavior prior to impact and after ricochet. After extensive data reduction, drag information was obtained for impact angles less than 10 deg. For 15 and 20 deg, the significant deflections and erratic behavior of the projectile could not be captured by the radar. In view of the criticality of this information, it is important that more reliable instrumentation be explored for further tests.

CONCLUSIONS

This report provides a technique to develop probabilistic SDZs that will be more accurate and more useful than current SDZs. There are, however, a number of follow-on efforts that must be conducted to make this new concept capable of dealing with all projectiles, training sites, and training scenarios. The key follow-on efforts are listed next.

The ricochet effort done as part of this study is primarily concentrated at nondeformable, spin-stabilized projectiles. Additional work is needed to study and model ricochet behavior of deformable projectiles and fin stabilized projectiles.

Impact media, as mentioned before, will play a significant role in effecting ricochet behavior. How it will effect it is not known, and further studies are needed especially if there is a requirement to produce SDZs for various impact media.

The computer program developed as part of this effort is very versatile and will produce probability based SDZs in a homogeneous environment with no particular consideration of the terrain. However, there is a definite need to upgrade this program so that it can be used to address variations in terrain.

The cost of testing for SDZ data collection, whether for ricochet or otherwise, is very expensive. To upgrade our present danger zones to fit the methodology and to produce future SDZs using this methodology will be very costly. One alternative is to use analogy between rounds, but to do that requires having a set of scaling laws that can be defended. This does not exist now and the cost to study and produce these laws will, in the long run, save the government a large amount of money in testing. This, without question, is needed for future SDZ development.

Table 1. Ricochet test data, .50-caliber, M33; at 100 m - sand

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
41	5	838	641	0.765	2.73	13.55	2.68	8.56	13.82
42	5	836	631	0.755	1.64	16.96	1.60	11.96	17.04
43	5	847	611	0.722	0.91	17.54	0.89	12.54	17.56
44	5	836	590	0.706	-0.91	18.79	-0.89	13.79	18.81
45	5	841	613	0.729	2.00	15.44	1.96	10.44	15.57
46	5	850	652	0.767	1.99	15.79	1.95	10.79	15.91
47	5	845	612	0.724	0.91	14.69	0.89	9.69	14.72
49	5	860	600	0.698	3.27	19.68	3.18	14.69	19.94
51	5	859	632	0.736	-0.62	17.73	-0.61	12.73	17.74
52	5	847	•	•	3.27	20.51	3.18	15.52	20.76
53	5	843	614	0.728	1.64	16.97	1.60	11.97	17.05
54	5	847	637	0.752	2.00	14.55	1.96	9.55	14.68
55	5	852	•	•	4.00	20.45	3.89	15.46	20.82
56	5	843	614	0.728	5.26	20.27	5.11	15.29	20.91
57	5	849	618	0.728	2.36	14.18	2.32	9.18	14.37
58	5	852	649	0.762	-0.73	14.80	-0.72	9.80	14.82
59	5	857	•	•	2.73	14.09	2.68	9.10	14.35
60	5	847	•	•	2.55	18.89	2.49	13.89	19.06
61	5	841	•	•	3.80	18.22	3.71	13.23	18.60
62	5	852	621	0.729	2.36	17.27	2.31	12.27	17.43
63	5	861	599	0.696	4.18	19.06	4.07	14.07	19.50
64	5	850	618	0.727	2.73	17.77	2.67	12.78	17.97
66	5	868	646	0.744	4.72	14.67	4.63	9.69	15.39
67	5	860	658	0.765	0.00	14.03	0.00	9.03	14.03
68	5	857	677	0.790	1.45	14.09	1.42	9.09	14.16
69	5	852	625	0.734	3.27	17.84	3.19	12.85	18.13
71	5	847	625	0.738	2.55	16.92	2.49	11.92	17.11
72	5	854	642	0.752	1.64	16.59	1.60	11.59	16.67
73	5	864	628	0.727	2.91	17.64	2.84	12.65	17.87
74	5	849	609	0.718	4.18	18.60	4.08	13.61	19.05
202	5	849	•	•	-0.73	15.28	-0.72	10.28	15.30
203	5	854	•	•	1.82	17.69	1.78	12.69	17.78
204	5	857	•	•	2.18	14.50	2.14	9.50	14.66
205	5	859	•	•	2.55	17.40	2.49	12.40	17.58
206	5	849	•	•	-3.63	17.08	-3.55	12.09	17.45
207	5	828	642	0.776	2.91	15.24	2.85	10.25	15.51
208	5	820	•	•	2.91	17.73	2.84	12.74	17.96
209	5	850	605	0.712	1.82	16.17	1.78	11.17	16.27
210	5	861	672	0.781	0.73	16.27	0.71	11.27	16.29
211	5	864	692	0.801	0.73	14.64	0.72	9.64	14.66
212	5	859	689	0.802	0.36	15.35	0.35	10.35	15.35
213	5	854	•	•	2.18	15.74	2.14	10.74	15.89
214	5	864	662	0.766	2.91	17.27	2.84	12.28	17.51
215	5	864	•	•	3.27	16.87	3.20	11.88	17.17
216	5	859	683	0.795	1.82	16.42	1.78	11.42	16.52
217	5	852	694	0.814	0.36	13.89	0.35	8.89	13.89
218	5	858	717	0.836	4.00	16.08	3.92	11.09	16.56
219	5	852	•	•	-0.36	16.87	-0.35	11.87	16.87
220	5	872	676	0.775	1.82	18.43	1.78	13.43	18.52
221	5	870	654	0.752	4.00	17.12	3.91	12.13	17.57
222	5	867	•	•	2.18	16.57	2.13	11.57	16.71
224	5	874	•	•	4.36	14.67	4.28	9.68	15.29
225	5	867	•	•	3.27	14.21	3.21	9.22	14.57
226	5	868	703	0.810	0.36	16.69	0.35	11.69	16.69
227	5	859	660	0.768	4.00	18.00	3.90	13.01	18.42
228	5	863	369	0.428	4.72	15.44	4.63	10.46	16.13
229	5	872	681	0.781	0.00	17.31	0.00	12.31	17.31
230	5	870	691	0.794	1.09	15.12	1.07	10.12	15.16

Table 1. (cont)

231	5	868	677	0.780	1.82	16.03	1.78	11.03	16.13
232	5	870	687	0.790	3.63	15.86	3.56	10.87	16.26
233	5	865	•	•	4.36	15.72	4.27	10.73	16.30
234	5	812	•	•	1.09	12.32	1.07	7.32	12.37
236	5	804	•	•	1.09	15.38	1.07	10.38	15.42
237	5	803	•	•	1.82	12.37	1.79	7.37	12.50
238	5	824	•	•	-10.79	16.44	-10.56	11.53	19.58
239	5	804	578	0.719	0.73	17.27	0.71	12.27	17.28
240	5	858	•	•	0.36	17.90	0.35	12.90	17.90
241	5	858	•	•	1.09	15.39	1.07	10.39	15.43
245	5	865	599	0.693	1.09	14.48	1.07	9.48	14.52
246	5	868	•	•	1.09	15.53	1.07	10.53	15.57
247	5	850	•	•	2.91	15.42	2.85	10.43	15.69
248	5	868	555	0.639	1.09	16.98	1.07	11.98	17.01
249	5	863	•	•	0.36	14.17	0.35	9.17	14.17
251	5	868	662	0.762	-0.36	15.12	-0.35	10.12	15.12
252	5	865	662	0.766	4.36	10.56	4.31	5.57	11.42
253	5	870	562	0.646	1.09	13.53	1.07	8.53	13.57
254	5	883	549	0.622	19.56	12.99	19.25	8.27	23.34
255	5	872	556	0.638	2.18	14.43	2.14	9.43	14.59
272	5	865	•	•	1.09	14.17	1.07	9.17	14.21
273	5	874	•	•	0.00	16.17	0.00	11.17	16.17
274	5	865	•	•	2.91	16.89	2.85	11.90	17.13
276	5	865	•	•	1.82	15.78	1.78	10.78	15.88
277	5	858	•	•	0.73	13.33	0.72	8.33	13.35
278	5	858	•	•	2.18	14.96	2.14	9.96	15.11
279	5	856	660	0.771	0.36	16.64	0.35	11.64	16.64
280	5	•	•	•	4.00	15.22	3.92	10.23	15.72
281	5	860	661	0.769	2.55	16.70	2.49	11.70	16.89
283	5	852	660	0.775	2.18	15.19	2.14	10.19	15.34
284	5	865	•	•	2.55	15.93	2.50	10.93	16.13
285	5	871	652	0.749	1.82	16.15	1.78	11.15	16.25
286	5	860	620	0.721	4.72	16.54	4.62	11.56	17.18
287	5	871	662	0.760	1.09	15.21	1.07	10.21	15.25
289	5	869	661	0.761	3.63	15.24	3.56	10.25	15.66
290	5	867	650	0.750	1.82	17.37	1.78	12.37	17.46
291	5	858	614	0.716	1.09	18.63	1.06	13.63	18.66
292	5	867	658	0.759	4.36	17.95	4.26	12.96	18.45
293	5	872	683	0.783	1.82	16.05	1.78	11.05	16.15
294	5	867	674	0.777	3.27	17.48	3.19	12.49	17.77
295	5	881	713	0.809	0.00	13.34	0.00	8.34	13.34
296	5	871	703	0.807	1.09	15.67	1.07	10.67	15.71
297	5	869	683	0.786	0.36	15.92	0.35	10.92	15.92
298	5	871	719	0.825	1.46	15.57	1.43	10.57	15.64
299	5	865	711	0.822	0.73	14.93	0.72	9.93	14.95
300	5	863	674	0.781	1.09	16.06	1.07	11.06	16.10
301	5	871	691	0.793	5.80	14.44	5.69	9.47	15.54
303	5	876	681	0.777	2.18	16.58	2.13	11.58	16.72
304	5	880	626	0.711	3.27	17.10	3.20	12.11	17.40
8	10	•	239	•	6.52	28.34	6.05	18.40	29.02
9	10	•	462	•	6.70	32.25	6.12	22.31	32.86
10	10	•	496	•	5.62	30.67	5.17	20.71	31.13
11	10	•	570	•	1.82	25.65	1.70	15.65	25.71
12	10	•	493	•	2.91	31.13	2.67	21.14	31.25
13	10	•	463	•	7.95	30.74	7.31	20.83	31.65
14	10	•	542	•	3.27	26.74	3.05	16.76	26.92
16	10	•	498	•	0.73	30.33	0.67	20.33	30.34
18	10	•	488	•	1.95	30.91	1.79	20.92	30.97
19	10	•	•	•	10.96	32.79	10.00	22.96	34.38
21	10	•	518	•	3.45	29.29	3.19	19.31	29.47

Table 1. (cont)

26	10	847	491	0.580	2.09	27.81	1.94	17.82	27.88
27	10	867	487	0.562	10.12	29.03	9.36	19.17	30.60
29	10	861	435	0.505	7.61	32.85	6.94	22.93	33.62
30	10	857	487	0.568	4.19	29.47	3.87	19.49	29.74
31	10	851	425	0.499	15.30	33.75	13.90	24.07	36.68
32	10	859	444	0.517	1.22	33.39	1.11	23.39	33.41
33	10	854	587	0.688	3.14	24.81	2.95	14.82	25.00
34	10	856	508	0.594	1.92	30.87	1.76	20.88	30.92
35	10	847	481	0.567	5.25	29.85	4.84	19.89	30.27
36	10	857	•	•	5.62	32.63	5.13	22.67	33.06
37	10	863	446	0.517	18.11	30.00	16.70	20.45	34.60
38	10	849	478	0.563	-6.88	27.77	-6.39	17.84	28.54
39	10	836	475	0.568	3.27	28.82	3.03	18.83	28.99
76	10	838	•	•	2.00	37.21	1.79	27.22	37.26
77	10	863	457	0.530	7.60	32.08	6.95	22.16	32.87
78	10	854	•	•	19.43	31.06	17.85	21.58	36.11
79	10	852	435	0.511	8.49	31.32	7.79	21.42	32.34
81	10	861	369	0.429	32.02	27.54	29.81	18.95	41.25
82	10	859	471	0.548	-2.18	31.77	-2.00	21.78	31.84
83	10	852	507	0.595	1.64	30.41	1.51	20.41	30.45
84	10	854	510	0.597	3.81	29.15	3.52	19.17	29.38
106	10	835	426	0.510	8.49	31.18	7.79	21.28	32.20
107	10	826	504	0.611	4.36	28.11	4.05	18.14	28.42
108	10	842	•	•	0.91	34.74	0.82	24.74	34.75
109	10	840	530	0.631	11.49	25.11	10.78	15.30	27.46
110	10	831	484	0.583	5.62	29.95	5.18	19.99	30.42
111	10	841	521	0.619	7.42	23.80	6.99	13.88	24.87
112	10	838	443	0.528	3.09	32.30	2.82	22.31	32.43
113	10	843	430	0.510	19.74	29.22	18.25	19.76	34.77
114	10	831	415	0.500	-2.73	30.16	-2.51	20.17	30.27
115	10	849	512	0.604	10.61	28.98	9.82	19.14	30.70
116	10	834	428	0.513	19.41	29.88	17.90	20.40	35.14
117	10	845	518	0.613	13.57	26.54	12.67	16.80	29.58
118	10	850	440	0.518	16.45	30.03	15.16	20.41	33.87
119	10	857	505	0.589	11.49	28.43	10.65	18.61	30.48
120	10	841	468	0.556	7.24	29.32	6.69	19.39	30.12
121	10	847	480	0.567	7.24	26.46	6.76	16.53	27.36
122	10	850	463	0.544	9.37	29.41	8.66	19.53	30.74
123	10	849	497	0.586	3.63	24.42	3.41	14.44	24.67
124	10	841	•	•	-0.91	35.41	-0.82	25.41	35.42
125	10	850	475	0.559	6.70	29.05	6.20	19.11	29.75
126	10	857	580	0.677	5.26	25.12	4.93	15.16	25.63
127	10	854	537	0.629	-10.79	22.62	-10.21	12.79	24.94
128	10	852	465	0.546	10.61	30.28	9.77	20.44	31.92
129	10	847	543	0.641	10.08	27.60	9.37	17.74	29.25
130	10	852	520	0.610	6.88	23.53	6.49	13.60	24.46
131	10	859	438	0.510	8.67	33.91	7.87	24.01	34.87
132	10	857	440	0.513	17.71	32.31	16.19	22.74	36.38
133	10	850	463	0.544	13.39	29.22	12.38	19.47	31.89
134	10	857	•	•	19.74	34.84	17.87	25.37	39.42
135	10	857	472	0.551	6.70	31.20	6.15	21.26	31.84
136	10	854	545	0.638	5.98	20.51	5.70	10.56	21.33
137	10	875	552	0.631	4.00	26.64	3.73	16.66	26.92
138	10	868	520	0.599	6.70	29.19	6.19	19.25	29.88
139	10	867	522	0.602	23.58	27.11	21.97	17.89	35.33
140	10	859	542	0.631	6.16	25.89	5.76	15.94	26.56
141	10	868	507	0.584	7.60	25.06	7.13	15.14	26.12
142	10	838	•	•	15.78	30.42	14.52	20.77	33.92
143	10	872	492	0.565	7.24	30.53	6.66	20.60	31.30
144	10	872	554	0.636	8.13	24.37	7.65	14.46	25.61

Table 1. (cont)

145	10	859	443	0.515	10.79	30.98	9.91	21.14	32.63
146	10	852	502	0.589	0.91	28.81	0.84	18.81	28.82
147	10	867	557	0.643	3.63	26.25	3.39	16.27	26.48
148	10	858	532	0.620	9.37	21.33	8.90	11.46	23.21
149	10	856	495	0.578	7.95	29.38	7.34	19.47	30.34
150	10	852	453	0.531	6.70	32.15	6.13	22.21	32.77
151	10	863	463	0.536	10.79	30.04	9.94	20.20	31.75
152	10	854	425	0.498	11.31	31.68	10.36	21.86	33.44
153	10	852	455	0.534	12.70	28.16	11.79	18.39	30.68
154	10	460	•	•	5.62	31.74	5.15	21.78	32.18
155	10	865	512	0.592	3.63	29.11	3.36	19.13	29.32
156	10	858	480	0.560	9.91	33.24	9.02	23.38	34.52
157	10	854	482	0.565	10.27	30.64	9.44	20.79	32.16
158	10	841	481	0.572	5.14	28.48	4.76	18.52	28.90
159	10	847	506	0.597	1.72	28.05	1.60	18.05	28.10
160	10	836	498	0.596	0.29	27.71	0.27	17.71	27.71
161	10	859	506	0.589	5.71	29.05	5.28	19.10	29.56
162	10	856	518	0.606	5.71	28.41	5.29	18.46	28.93
163	10	854	475	0.557	7.41	30.62	6.81	20.70	31.42
164	10	850	520	0.611	1.15	28.95	1.06	18.95	28.97
165	10	843	503	0.597	0.29	28.29	0.27	18.29	28.29
166	10	847	•	•	12.41	32.15	11.35	22.36	34.22
167	10	847	•	•	7.13	36.70	6.40	26.77	37.29
168	10	856	499	0.583	0.57	28.82	0.53	18.82	28.83
169	10	849	534	0.629	2.29	26.82	2.14	16.83	26.91
170	10	863	444	0.515	8.25	32.22	7.54	22.31	33.15
171	10	858	484	0.564	3.15	29.67	2.91	19.68	29.82
172	10	868	441	0.508	5.99	32.13	5.48	22.18	32.62
173	10	872	•	•	2.00	34.30	1.81	24.31	34.35
174	10	858	484	0.564	2.00	30.48	1.84	20.49	30.54
175	10	859	461	0.537	3.43	33.72	3.12	23.74	33.87
176	10	858	504	0.588	3.15	26.21	2.94	16.22	26.39
178	10	877	450	0.513	7.97	31.52	7.30	21.61	32.41
179	10	863	•	•	17.22	29.87	15.88	20.28	34.08
180	10	875	557	0.636	6.28	28.10	5.83	18.16	28.74
181	10	884	479	0.541	3.72	31.66	3.41	21.68	31.86
182	10	862	499	0.580	46.67	20.70	44.45	13.69	50.07
183	10	863	532	0.617	-1.43	27.23	-1.33	17.23	27.26
185	10	860	442	0.514	3.43	34.45	3.11	24.47	34.60
186	10	849	569	0.670	0.29	23.46	0.27	13.46	23.46
187	10	856	•	•	23.99	33.43	21.84	24.21	40.32
188	10	854	534	0.625	5.43	25.91	5.08	15.95	26.43
189	10	863	534	0.618	2.86	27.80	2.66	17.81	27.94
190	10	874	428	0.490	12.41	31.12	11.39	21.33	33.27
191	10	863	•	•	10.20	36.04	9.18	26.18	37.27
192	10	872	495	0.567	7.41	30.26	6.82	20.34	31.07
193	10	856	465	0.543	9.65	25.79	9.03	15.92	27.42
194	10	867	510	0.589	4.57	29.57	4.22	19.60	29.89
195	10	871	513	0.590	9.09	27.82	8.45	17.94	29.15
22	15	843	•	•	6.03	44.38	4.95	29.45	44.70
23	15	841	•	•	•	•	•	•	•
24	15	849	302	0.356	•	•	•	•	•
25	15	859	364	0.424	•	•	•	•	•
86	15	837	280	0.335	9.61	46.57	7.76	31.74	47.33
87	15	•	•	•	15.30	42.44	12.73	27.88	44.62
88	15	838	290	0.346	18.88	47.66	15.12	33.30	50.41
89	15	840	290	0.345	•	•	•	•	•
90	15	840	346	0.412	7.78	38.98	6.62	24.10	39.63
91	15	841	315	0.374	26.04	44.52	21.36	30.76	50.16
92	15	852	293	0.344	23.89	45.55	19.45	31.59	50.19

Table 1. (cont)

93	15	841	336	0.399	•	•	•	•	•
94	15	849	301	0.355	34.24	42.29	28.55	29.45	52.30
95	15	850	256	0.301	4.46	49.34	3.52	34.38	49.49
96	15	859	277	0.322	20.37	42.44	16.95	28.21	46.22
97	15	838	401	0.478	10.15	47.61	8.13	32.80	48.42
98	15	849	346	0.408	13.55	47.46	10.86	32.79	48.91
99	15	854	321	0.376	•	•	•	•	•
100	15	856	309	0.361	39.60	32.54	35.03	20.58	49.49
101	15	850	272	0.320	•	•	•	•	•
102	15	838	350	0.418	20.37	45.55	16.58	31.31	48.97
103	15	847	347	0.410	47.75	31.79	42.43	21.16	55.15
104	15	857	332	0.387	•	•	•	•	•
105	15	848	351	0.414	39.82	44.27	32.79	32.13	56.63
549	15	•	•	•	-17.28	45.06	-14.11	30.61	47.59
550	15	•	•	•	-2.91	32.85	-2.57	17.87	32.96
551	15	•	•	•	18.93	36.98	16.31	22.67	40.92
552	15	•	•	•	-7.24	45.72	-5.88	30.82	46.16
553	15	•	•	•	8.67	44.43	7.11	29.57	45.09
557	15	883	•	•	18.43	46.52	14.89	32.14	49.25
558	15	857	•	•	20.22	37.61	17.36	23.40	41.98
560	15	883	•	•	5.08	48.23	4.05	33.28	48.43
561	15	863	•	•	•	•	•	•	•
562	15	876	•	•	•	•	•	•	•
565	15	•	•	•	20.86	52.94	15.96	38.69	55.73
567	15	898	•	•	2.91	50.04	2.28	35.06	50.10
568	15	871	•	•	0.36	48.64	0.29	33.64	48.64
569	15	866	•	•	-7.24	47.87	-5.78	32.96	48.28
570	15	871	•	•	-7.24	50.56	-5.65	35.65	50.93
571	15	875	•	•	19.58	54.13	14.80	39.78	56.49
572	15	862	•	•	25.01	45.05	20.44	31.19	50.19
573	15	882	•	•	2.18	47.15	1.75	32.16	47.19
574	15	864	•	•	11.14	50.42	8.71	35.64	51.31
575	15	882	•	•	-31.23	44.35	-25.67	31.13	52.30
576	15	•	•	•	23.35	53.74	17.73	39.67	57.11
577	15	•	•	•	-11.49	54.91	-8.61	40.13	55.71
578	15	•	•	•	18.27	57.01	13.40	42.56	58.87
579	15	•	•	•	33.69	49.64	26.59	36.62	57.40
581	15	•	•	•	22.74	49.04	18.01	34.96	52.80
582	15	•	•	•	18.76	42.73	15.58	28.39	45.93
584	15	•	•	•	1.99	44.27	1.63	29.28	44.31
589	15	•	•	•	17.94	42.15	14.95	27.75	45.14
592	15	882	•	•	-17.61	52.46	-13.53	38.00	54.50
596	20	871	87	0.100	-8.14	56.01	-6.03	41.12	56.40
597	20	873	59	0.068	15.45	46.15	12.51	31.58	48.11
598	20	874	97	0.111	10.49	54.37	7.91	39.56	55.05
599	20	862	•	•	•	•	•	•	•
600	20	867	•	•	•	•	•	•	•
601	20	882	117	0.133	13.61	53.11	10.39	38.43	54.31
602	20	893	•	•	•	•	•	•	•
603	20	878	36	0.040	27.35	38.75	23.32	25.17	46.16
604	20	871	53	0.061	-3.77	45.22	-3.07	30.25	45.34
605	20	885	•	•	•	•	•	•	•
606	20	885	40	0.045	2.73	61.12	1.90	46.13	61.16
607	20	893	•	•	•	•	•	•	•
608	20	885	49	0.056	32.16	54.34	24.31	41.08	60.43
609	20	885	43	0.049	10.92	50.24	8.55	35.45	51.10
610	20	893	38	0.042	9.36	58.60	6.74	43.74	59.06
611	20	885	30	0.033	12.15	51.64	9.40	36.90	52.65
612	20	883	38	0.042	-7.56	62.28	-5.18	47.37	62.54
613	20	893	24	0.027	30.22	48.67	24.03	35.28	55.20

Table 1. (cont)

614	20	893	32	0.035	38.53	49.99	30.35	37.57	59.80
615	20	878	77	0.088	19.38	56.81	14.25	42.43	58.91
616	20	887	73	0.082	-14.04	61.90	-9.68	47.21	62.81
617	20	894	81	0.090	8.18	57.37	5.97	42.48	57.74
618	20	879	•	•	-13.61	57.20	-9.96	42.51	58.23
619	20	868	•	•	•	•	•	•	•
620	20	887	•	•	•	•	•	•	•
621	20	887	•	•	•	•	•	•	•
622	20	864	•	•	•	•	•	•	•
623	20	887	•	•	•	•	•	•	•
624	20	871	•	•	•	•	•	•	•
625	20	894	99	0.111	9.88	53.46	7.51	38.63	54.09
626	20	887	•	•	•	•	•	•	•
627	20	871	•	•	•	•	•	•	•
628	20	879	•	•	•	•	•	•	•
629	20	887	117	0.131	-12.14	65.90	-7.86	51.12	66.47
630	20	887	95	0.107	4.59	51.75	3.55	36.79	51.89
631	20	879	•	•	•	•	•	•	•
632	20	879	87	0.099	34.27	46.39	27.76	33.49	55.25
633	20	902	•	•	11.14	54.12	8.42	39.33	54.90
634	20	887	•	•	•	•	•	•	•
635	20	887	80	0.090	-1.89	57.32	-1.38	42.33	57.34
636	20	867	73	0.084	-6.74	51.85	-5.20	36.93	52.16
637	20	902	•	•	•	•	•	•	•
638	20	887	•	•	26.29	57.01	19.30	43.14	60.78
639	20	879	80	0.091	7.53	60.07	5.32	45.16	60.35
640	20	879	•	•	•	•	•	•	•
641	20	887	•	•	-14.01	54.68	-10.53	40.01	55.88
642	20	887	73	0.082	21.98	57.36	16.06	43.15	59.99
643	20	887	117	0.131	-14.14	54.45	-10.65	39.79	55.68
644	20	887	•	•	•	•	•	•	•
645	20	879	87	0.099	12.39	58.95	8.88	44.20	59.75

Table 2. Ricochet test data, .50-caliber, M33; at 200 m - sand

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
730	5	875	578	0.661	3.63	6.18	3.61	1.19	7.16
732	5	868	823	0.948	-15.95	•	•	•	•
736	5	881	838	0.951	1.09	14.61	1.07	9.71	14.75
740	5	875	831	0.949	17.94	12.05	17.69	7.33	21.53
741	5	870	826	0.950	0.54	16.77	0.53	11.95	16.96
717	10	870	584	0.671	6.52	31.65	6.07	23.18	33.71
718	10	874	581	0.664	4.53	27.71	4.25	18.50	28.81
719	10	873	582	0.667	2.91	28.30	2.73	19.16	29.28
720	10	870	584	0.671	2.91	29.74	2.72	20.83	30.95
722	10	873	580	0.664	3.27	26.42	3.08	17.03	27.20
723	10	880	575	0.654	6.16	32.82	5.72	24.62	35.07
724	10	875	577	0.659	-14.77	22.21	-14.05	12.78	26.71
725	10	873	580	0.664	3.63	27.57	3.41	18.33	28.53
728	10	872	585	0.671	12.18	27.60	11.44	18.58	30.73
729	10	873	581	0.665	18.93	33.39	17.61	25.91	39.79
692	15	849	609	0.716	0.00	34.39	0.00	19.39	34.39
693	15	851	606	0.712	-24.87	34.00	-22.44	21.67	42.76
694	15	850	607	0.714	-3.27	35.02	-2.92	21.45	36.56
695	15	851	610	0.716	2.18	38.09	1.94	25.36	40.40
696	15	851	607	0.713	2.91	35.31	2.60	21.80	36.89
699	15	851	604	0.710	19.58	38.24	17.47	26.55	44.88
700	15	962	593	0.617	7.95	42.37	7.01	31.60	47.09
701	15	868	592	0.682	42.53	30.92	39.10	20.73	52.45
702	15	858	599	0.698	26.64	38.21	23.88	27.37	48.29
703	15	861	596	0.692	4.91	44.70	4.32	35.18	50.35
704	15	859	598	0.696	14.59	35.66	13.06	22.74	39.85
705	15	870	588	0.676	20.70	36.05	18.55	23.77	42.80
706	15	872	586	0.673	18.60	35.44	16.68	22.79	41.17
707	15	868	589	0.679	8.31	42.19	7.33	31.35	46.88
709	15	871	586	0.674	8.31	44.58	7.32	35.12	50.60
710	15	859	600	0.699	12.70	41.59	11.23	30.71	46.97
711	15	872	588	0.674	-5.80	41.61	-5.12	30.38	45.64
712	15	873	584	0.669	24.41	38.63	21.83	27.65	47.61
713	15	862	595	0.690	28.08	41.17	25.13	31.86	52.69
714	15	871	586	0.674	7.78	38.22	6.91	25.68	41.23
715	15	870	588	0.676	17.61	41.90	15.61	31.60	48.95
716	15	873	585	0.670	12.53	43.96	11.06	34.38	50.49

Table 3. Ricochet test data, .50-caliber, M33; at 100 m - steel

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
256	5	867	839	0.968	0.36	6.34	0.36	1.34	6.35
257	5	839	811	0.967	0.73	5.92	0.73	0.92	5.96
258	5	•	•	•	0.36	6.40	0.36	1.40	6.41
259	5	861	826	0.959	13.22	6.12	13.15	1.25	14.54
261	5	878	809	0.921	1.09	6.13	1.08	1.13	6.23
262	5	882	854	0.968	1.46	5.45	1.45	0.45	5.45
263	5	860	829	0.964	0.36	5.80	0.36	0.80	5.81
265	5	878	838	0.954	0.73	5.77	0.73	0.77	5.82
266	5	880	838	0.952	0.73	6.60	0.73	1.60	6.64
267	5	878	846	0.964	1.82	5.82	1.81	0.82	6.10
268	5	874	832	0.952	1.82	5.29	1.81	0.29	5.59
269	5	876	853	0.974	2.18	5.31	2.17	0.31	5.74
270	5	868	843	0.971	0.73	6.16	0.73	1.16	6.20
271	5	878	848	0.966	1.09	5.44	1.09	0.44	5.55
305	5	855	843	0.986	0.00	7.11	0.00	2.11	7.11
306	5	861	842	0.978	1.46	6.77	1.45	1.77	6.92
308	5	852	839	0.985	0.73	7.13	0.72	2.13	7.17
309	5	865	847	0.979	0.73	8.02	0.72	3.02	8.05
310	5	865	840	0.971	0.36	7.49	0.36	2.49	7.50
312	5	855	846	0.989	0.73	6.84	0.73	1.84	6.88
313	5	868	821	0.946	0.36	6.07	0.36	1.07	6.08
314	5	858	831	0.969	0.00	7.22	0.00	2.22	7.22
316	5	868	839	0.967	1.46	•	•	•	•
318	5	868	838	0.965	0.00	14.54	0.00	9.54	14.54
320	5	858	832	0.970	0.36	7.55	0.36	2.55	7.56
323	5	861	829	0.963	1.46	14.63	1.43	9.63	14.63
324	10	865	•	•	0.73	12.45	0.71	2.45	12.47
325	10	855	770	0.901	0.00	12.54	0.00	2.54	12.54
326	10	862	787	0.913	0.36	12.37	0.35	2.37	12.38
327	10	862	785	0.911	-3.63	13.12	-3.54	3.14	13.60
328	10	856	844	0.986	1.09	12.46	1.07	2.46	12.51
329	10	862	764	0.886	0.73	12.98	0.71	2.98	13.00
330	10	874	839	0.960	1.46	11.89	1.43	1.89	11.98
331	10	869	821	0.945	-4.00	12.76	-3.91	2.78	13.36
332	10	867	819	0.945	1.46	12.74	1.43	2.74	12.82
333	10	874	787	0.900	1.09	12.76	1.06	2.76	12.81
334	10	871	776	0.891	1.09	12.81	1.06	2.81	12.86
335	10	871	784	0.900	1.09	12.40	1.07	2.40	12.45
336	10	869	791	0.910	0.73	12.89	0.71	2.89	12.91
337	10	860	791	0.920	1.46	14.58	1.42	4.58	14.65
339	10	858	824	0.960	0.36	11.75	0.35	1.75	11.76
340	10	843	792	0.940	0.73	12.39	0.71	2.39	12.41
342	10	854	757	0.886	1.09	12.19	1.07	2.19	12.24
343	10	849	735	0.866	1.09	11.88	1.07	1.88	11.93
344	10	858	745	0.868	0.36	11.90	0.35	1.90	11.91
345	10	856	775	0.905	0.36	12.45	0.35	2.45	12.46
346	10	858	809	0.943	1.09	12.17	1.07	2.17	12.22
347	10	852	691	0.811	9.73	12.64	9.50	2.78	15.90
348	10	863	758	0.878	0.36	12.35	0.35	2.35	12.36
349	10	867	808	0.932	1.46	11.83	1.43	1.83	11.92
350	10	872	799	0.916	1.09	11.91	1.07	1.91	11.96
351	10	845	774	0.916	1.46	12.62	1.43	2.62	12.70
352	10	859	765	0.891	0.73	11.58	0.72	1.58	11.60
353	10	862	748	0.868	1.09	11.83	1.07	1.83	11.88
354	10	874	811	0.928	0.00	11.87	0.00	1.87	11.87
355	10	860	768	0.893	0.00	11.79	0.00	1.79	11.79
356	10	863	765	0.886	-0.36	11.47	-0.35	1.47	11.48
357	10	852	772	0.906	0.36	11.84	0.35	1.84	11.85
358	10	845	802	0.949	0.00	11.91	0.00	1.91	11.91

Table 3. (cont)

359	10	852	785	0.921	-0.36	11.35	-0.35	1.35	11.36
360	10	849	776	0.914	0.73	12.49	0.71	2.49	12.51
361	10	854	801	0.938	0.00	12.28	0.00	2.28	12.28
362	10	852	807	0.947	-7.24	15.89	-7.00	5.97	17.42
363	10	860	782	0.909	0.36	11.86	0.35	1.86	11.87
364	10	856	794	0.928	1.09	11.99	1.07	1.99	12.04
365	10	852	814	0.955	1.46	12.52	1.43	2.52	12.60
366	10	858	827	0.964	0.73	12.09	0.71	2.09	12.11
367	10	861	772	0.897	1.09	12.07	1.07	2.07	12.12
368	10	872	838	0.961	0.36	12.04	0.35	2.04	12.05
369	10	820	•	•	0.73	11.98	0.71	1.98	12.00
370	10	802	•	•	1.27	11.84	1.24	1.84	11.91
371	10	865	818	0.946	1.46	12.26	1.43	2.26	12.35
372	10	870	826	0.949	1.27	12.20	1.24	2.20	12.26
373	10	•	•	•	1.46	11.54	1.43	1.54	11.63
374	10	•	•	•	1.09	12.28	1.07	2.28	12.33
375	10	•	•	•	0.36	12.07	0.35	2.07	12.08
376	10	855	838	0.980	1.46	11.21	1.43	1.21	11.30
377	10	851	834	0.980	0.36	11.97	0.35	1.97	11.98
378	10	864	811	0.939	0.73	11.98	0.71	1.98	12.00
379	10	855	782	0.915	1.46	11.97	1.43	1.97	12.06
380	10	855	775	0.906	0.19	11.76	0.19	1.76	11.76
381	10	856	783	0.915	0.36	11.03	0.35	1.03	11.04
382	10	862	790	0.916	1.46	12.42	1.43	2.42	12.50
383	10	871	781	0.897	1.82	12.22	1.78	2.22	12.35
384	10	858	818	0.953	1.09	12.56	1.06	2.56	12.61
385	10	856	811	0.947	-6.52	12.45	-6.37	2.51	14.03
386	10	863	823	0.954	0.73	11.41	0.72	1.41	11.43
387	10	865	824	0.953	1.46	12.67	1.43	2.67	12.75
388	10	856	807	0.943	1.46	11.72	1.43	1.72	11.81
389	10	858	807	0.941	0.73	12.38	0.71	2.38	12.40
390	10	865	816	0.943	1.09	11.83	1.07	1.83	11.88
391	10	861	814	0.945	0.36	11.85	0.35	1.85	11.86
392	10	847	758	0.895	0.36	11.62	0.35	1.62	11.63
393	10	867	760	0.877	0.73	12.31	0.71	2.31	12.33
394	10	854	807	0.945	1.09	12.08	1.07	2.08	12.13
395	10	852	757	0.888	1.09	12.42	1.07	2.42	12.47
396	10	865	•	•	1.09	11.53	1.07	1.53	11.58
397	10	862	820	0.951	1.09	12.58	1.06	2.58	12.63
398	10	857	814	0.950	1.09	11.66	1.07	1.66	11.71
399	10	866	830	0.958	1.09	12.48	1.07	2.48	12.53
400	10	864	826	0.956	1.46	11.51	1.43	1.51	11.60
401	10	866	818	0.945	1.46	12.16	1.43	2.16	12.25
402	10	868	832	0.959	0.73	11.59	0.72	1.59	11.61
403	10	853	816	0.957	0.73	12.18	0.71	2.18	12.20
404	10	862	838	0.972	1.82	11.95	1.78	1.95	12.09
405	10	873	825	0.945	1.09	11.64	1.07	1.64	11.69
406	10	864	816	0.944	0.73	12.75	0.71	2.75	12.77
408	10	866	826	0.954	0.36	11.98	0.35	1.98	11.99
409	10	871	836	0.960	1.09	12.60	1.06	2.60	12.65
410	10	873	823	0.943	-1.09	12.70	-1.06	2.70	12.75
411	10	864	826	0.956	1.09	11.76	1.07	1.76	11.81
412	10	877	822	0.937	1.09	12.02	1.07	2.02	12.07
413	10	871	830	0.953	1.46	12.14	1.43	2.14	12.23
414	10	860	825	0.959	1.09	13.22	1.06	3.22	13.26
415	10	878	827	0.942	1.46	11.64	1.43	1.64	11.73
416	10	872	829	0.951	0.73	11.80	0.71	1.80	11.82
417	10	870	831	0.955	1.09	11.22	1.07	1.22	11.27
418	10	867	826	0.953	1.82	10.91	1.79	0.91	11.06
419	10	868	838	0.965	1.82	12.30	1.78	2.30	12.43

Table 3. (cont)

420	10	881	825	0.936	1.64	11.66	1.61	1.66	11.77
421	10	870	828	0.952	1.09	11.15	1.07	1.15	11.20
422	10	871	829	0.952	1.82	11.69	1.78	1.69	11.83
423	10	870	822	0.945	2.18	11.87	2.13	1.88	12.07
424	10	880	838	0.952	1.46	10.83	1.43	0.83	10.93
425	10	867	822	0.948	1.09	12.41	1.07	2.41	12.46
426	10	872	829	0.951	1.46	12.05	1.43	2.05	12.14
427	10	870	822	0.945	1.46	12.48	1.43	2.48	12.56
428	10	856	789	0.922	1.46	11.68	1.43	1.68	11.77
430	10	870	827	0.951	2.18	11.90	2.13	1.91	12.10
431	10	872	835	0.958	2.18	10.66	2.14	0.67	10.88
432	10	872	825	0.946	2.18	11.48	2.14	1.49	11.68
433	10	879	796	0.906	1.09	12.14	1.07	2.14	12.19
434	10	863	822	0.952	1.46	11.04	1.43	1.04	11.13
435	10	858	818	0.953	1.09	12.13	1.07	2.13	12.18
436	15	860	779	0.906	-3.63	17.21	-3.47	2.24	17.58
437	15	861	759	0.882	-4.36	17.65	-4.16	2.69	18.16
438	15	878	766	0.872	-4.54	17.02	-4.34	2.06	17.60
439	15	871	774	0.889	-4.36	18.52	-4.14	3.56	19.01
440	15	871	•	•	-3.81	18.43	-3.62	3.46	18.81
441	15	871	795	0.913	-3.63	17.72	-3.46	2.75	18.08
442	15	885	802	0.906	-4.18	18.64	-3.97	3.68	19.09
443	15	893	837	0.937	-2.91	17.15	-2.78	2.17	17.39
444	15	878	816	0.929	-3.63	17.96	-3.46	2.99	18.31
445	15	885	837	0.946	-3.27	16.72	-3.13	1.74	17.03
446	15	871	809	0.929	-3.27	16.84	-3.13	1.86	17.15
447	15	892	816	0.915	-3.63	17.08	-3.47	2.11	17.45
448	15	871	•	•	-3.45	18.26	-3.28	3.29	18.57
449	15	863	•	•	-3.45	18.60	-3.28	3.63	18.91
450	15	885	816	0.922	-4.00	18.45	-3.80	3.48	18.86
451	15	885	802	0.906	-3.45	17.38	-3.30	2.41	17.71
452	15	884	816	0.923	-4.36	18.13	-4.15	3.17	18.63
453	15	873	781	0.895	-4.36	17.89	-4.15	2.93	18.40
504	15	872	816	0.936	-0.36	18.24	-0.34	3.24	18.24
505	15	886	831	0.938	-1.82	17.22	-1.74	2.23	17.31
506	15	885	823	0.930	-2.00	18.84	-1.90	3.85	18.94
507	15	894	839	0.938	-1.09	17.41	-1.04	2.41	17.44
508	15	892	827	0.927	-0.73	17.58	-0.70	2.58	17.59
509	15	890	838	0.942	-1.09	17.93	-1.04	2.93	17.96
510	15	883	816	0.924	-1.27	18.29	-1.21	3.29	18.33
511	15	883	836	0.947	-1.46	19.12	-1.38	4.12	19.17
512	15	886	827	0.933	-1.82	19.42	-1.72	4.43	19.50
513	15	883	825	0.934	-1.27	18.35	-1.21	3.35	18.39
514	15	890	834	0.937	-1.09	18.04	-1.04	3.04	18.07
515	15	899	834	0.928	-1.27	18.60	-1.21	3.60	18.64
479	20	872	805	0.923	-1.46	21.98	-1.35	1.98	21.98
480	20	875	801	0.915	-1.09	23.51	-1.00	3.51	23.53
481	20	877	815	0.929	-0.73	22.37	-0.68	2.37	22.38
482	20	875	795	0.909	-1.09	24.16	-1.00	4.16	24.18
483	20	877	811	0.925	-0.73	22.91	-0.67	2.91	22.92
484	20	868	795	0.916	-1.09	23.13	-1.00	3.13	23.15
485	20	876	818	0.934	-0.18	22.64	-0.17	2.64	22.64
486	20	864	804	0.931	0.00	26.42	0.00	6.42	26.42
487	20	865	801	0.926	-0.91	22.44	-0.84	2.44	22.46
488	20	872	795	0.912	0.36	23.07	0.33	3.07	23.07
489	20	875	815	0.931	-0.73	22.30	-0.68	2.30	22.31
490	20	873	804	0.921	11.14	22.63	10.29	2.97	25.09
491	20	872	795	0.912	-0.73	23.72	-0.67	3.72	23.73
492	20	877	811	0.925	-1.82	23.26	-1.67	3.27	23.33
493	20	875	797	0.911	-1.09	22.91	-1.01	2.91	22.93

Table 3. (cont)

494	20	873	795	0.911	-1.46	22.85	-1.35	2.86	22.89
495	20	881	814	0.924	0.18	24.02	0.16	4.02	24.02
496	20	883	813	0.921	-0.55	22.71	-0.51	2.71	22.71
497	20	873	797	0.913	0.00	22.96	0.00	2.96	22.96
498	20	883	800	0.906	-1.27	22.43	-1.17	2.43	22.46
499	20	877	824	0.940	-0.73	26.87	-0.66	6.87	26.88
500	20	890	809	0.909	-1.46	22.52	-1.35	2.53	22.56
501	20	877	803	0.916	-0.36	24.89	-0.33	4.89	24.89
502	20	879	793	0.902	-1.09	22.32	-1.01	2.32	22.35
503	20	886	804	0.907	-0.73	22.97	-0.67	2.97	22.98
454	25	873	776	0.889	1.82	28.29	1.61	3.30	28.34
455	25	883	786	0.890	1.46	28.84	1.28	3.85	28.87
456	25	878	775	0.883	1.82	28.84	1.60	3.85	28.89
457	25	870	768	0.883	1.27	29.43	1.11	4.44	29.45
458	25	877	753	0.859	2.55	29.28	2.23	4.30	29.38
459	25	868	755	0.870	0.36	28.76	0.32	3.76	28.76
460	25	881	778	0.883	0.73	29.54	0.64	4.54	29.55
461	25	873	776	0.889	1.27	28.87	1.11	3.88	28.90
462	25	864	741	0.858	1.46	29.17	1.28	4.18	29.20
463	25	877	749	0.854	1.82	29.37	1.59	4.38	29.42
464	25	868	760	0.876	0.36	30.03	0.31	5.03	30.03
465	25	870	773	0.889	2.18	29.43	1.90	4.45	29.50
466	25	866	764	0.882	1.09	30.14	0.95	5.14	30.16
467	25	877	758	0.864	2.55	28.86	2.24	3.88	28.96
468	25	866	732	0.845	1.46	30.95	1.26	5.96	30.98
469	25	875	778	0.889	1.46	29.41	1.28	4.42	29.44
470	25	868	757	0.872	0.73	28.85	0.64	3.85	28.86
471	25	871	759	0.871	2.55	29.64	2.22	4.66	29.74
472	25	866	771	0.890	-0.36	29.41	-0.31	4.41	29.41
473	25	886	790	0.892	0.00	28.15	0.00	3.15	28.15
474	25	873	746	0.855	2.55	28.99	2.24	4.01	29.09
475	25	864	749	0.867	1.82	28.98	1.60	3.99	29.03
476	25	873	760	0.871	1.82	29.35	1.59	4.36	29.40
477	25	875	786	0.898	1.46	29.09	1.28	4.10	29.12
478	25	873	774	0.887	1.46	30.28	1.27	5.29	30.31
516	30	890	742	0.834	-0.73	37.99	-0.58	7.99	38.00
517	30	879	732	0.833	-1.09	37.38	-0.87	7.38	37.39
518	30	866	733	0.846	3.27	40.87	2.52	10.91	40.98
519	30	859	729	0.849	3.27	41.09	2.51	11.13	41.20
520	30	865	736	0.851	1.09	39.85	0.85	9.85	39.86
521	30	859	717	0.835	1.46	41.28	1.12	11.29	41.30
522	30	860	726	0.844	1.09	40.29	0.85	10.29	40.30
523	30	864	729	0.844	0.36	41.15	0.28	11.15	41.15
524	30	873	736	0.843	2.91	41.00	2.24	11.03	41.08
525	30	873	726	0.832	4.00	41.27	3.07	11.32	41.43
526	30	873	722	0.827	4.18	40.99	3.21	11.05	41.17
527	30	865	739	0.854	1.09	40.75	0.84	10.75	40.76
528	30	868	704	0.811	5.80	37.16	4.66	7.28	37.55
529	30	872	676	0.775	1.46	40.72	1.13	10.73	40.74
530	30	855	694	0.812	19.74	39.27	15.43	10.59	43.22
531	30	868	721	0.831	2.18	41.30	1.67	11.32	41.35
532	30	878	745	0.849	1.27	41.88	0.97	11.89	41.90
533	30	883	753	0.853	1.82	40.21	1.41	10.22	40.24
534	30	860	731	0.850	1.46	40.33	1.13	10.34	40.35
535	30	862	721	0.836	0.91	41.16	0.70	11.16	41.17
536	30	877	732	0.835	3.27	40.75	2.52	10.79	40.86
537	30	875	696	0.795	1.64	40.41	1.27	10.42	40.44
538	30	873	712	0.816	1.09	40.83	0.84	10.83	40.84
539	30	882	729	0.827	1.64	40.58	1.27	10.59	40.61
540	30	883	745	0.844	1.64	40.75	1.26	10.76	40.78

Table 3. (cont)

541	30	862	726	0.842	2.55	40.27	1.98	10.29	40.34
542	30	866	732	0.845	1.64	40.55	1.27	10.56	40.58
543	30	866	700	0.808	-1.82	42.26	-1.38	12.27	42.29
544	30	877	719	0.820	2.91	41.65	2.22	11.68	41.73
545	30	870	721	0.829	4.72	41.19	3.62	11.26	41.41
546	40	870	654	0.752	3.51	42.61	2.59	2.66	42.73
547	40	863	629	0.729	-3.24	43.02	-2.37	3.06	43.12
548	40	868	657	0.757	1.56	44.71	1.11	4.72	44.73
549	40	858	676	0.788	4.99	48.93	3.32	9.02	49.12
550	40	858	640	0.746	1.64	57.74	0.92	17.75	57.75
551	40	868	651	0.750	1.66	49.06	1.10	9.07	49.08
552	40	864	623	0.721	-3.07	41.17	-2.31	1.21	41.26
553	40	868	673	0.775	2.49	46.83	1.72	6.85	46.88
554	40	861	600	0.697	0.87	47.89	0.59	7.89	47.90
555	40	874	612	0.700	-8.43	53.47	-5.15	13.71	53.93
556	40	887	640	0.722	6.41	58.60	3.52	18.73	58.82
557	40	870	651	0.748	-8.68	52.42	-5.41	12.68	52.92
558	40	877	640	0.730	-0.37	52.75	-0.23	12.75	52.75
559	40	874	662	0.757	5.31	52.89	3.28	12.99	53.08
560	40	877	657	0.749	-2.13	51.80	-1.35	11.82	51.83
561	40	867	588	0.678	-10.73	51.49	-6.80	11.90	52.28
562	40	884	621	0.702	-7.54	49.79	-4.93	10.00	50.21
563	40	884	711	0.804	-3.97	48.38	-2.66	8.44	48.50
564	40	874	650	0.744	-1.90	43.65	-1.38	3.66	43.68
565	40	880	648	0.736	3.02	56.38	1.74	16.41	56.43
566	45	877	643	0.733	-1.38	65.22	-0.62	20.23	65.23
567	45	887	600	0.676	11.89	58.18	6.42	13.65	58.94
568	45	877	623	0.710	1.53	60.73	0.78	15.74	60.74
569	45	874	648	0.741	2.69	60.83	1.36	15.85	60.87
570	45	890	625	0.702	-1.31	45.76	-0.91	0.77	45.77
571	45	884	597	0.675	-5.46	61.32	-2.73	16.41	61.46
572	45	874	586	0.670	12.49	62.23	6.07	17.70	62.94
573	45	894	651	0.728	7.95	55.18	4.61	10.41	55.56
574	45	884	645	0.730	3.75	60.10	1.94	15.14	60.17
575	45	880	637	0.724	0.00	56.04	0.00	11.04	56.04
576	50	874	667	0.763	5.58	69.20	2.10	19.28	69.30
577	50	869	637	0.733	-1.79	61.15	-0.88	11.16	61.17
578	50	884	549	0.621	12.51	51.64	7.73	2.29	52.71
579	50	876	534	0.610	•	•	•	•	•
580	50	884	564	0.638	•	•	•	•	•
581	50	887	555	0.626	•	•	•	•	•

Table 4. Ricochet test data, 9-mm, M882; at 50 m - sand

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
249	5	340	191	0.56	5.25	15.24	5.15	10.26	16.10
250	5	331	232	0.70	1.82	11.01	1.80	6.01	11.16
251	5	335	229	0.68	3.27	12.78	3.22	7.79	13.18
252	5	336	216	0.64	3.27	13.62	3.21	8.63	14.00
253	5	336	230	0.68	2.91	11.49	2.87	6.50	11.85
254	5	333	227	0.68	3.08	10.39	3.04	5.40	10.83
255	5	335	239	0.71	2.91	11.46	2.87	6.47	11.82
256	5	331	188	0.57	3.08	14.55	3.02	9.56	14.87
257	5	338	230	0.68	1.82	11.67	1.79	6.67	11.81
258	5	336	184	0.55	5.44	15.80	5.33	10.82	16.69
259	5	335	209	0.62	2.73	12.52	2.69	7.53	12.81
260	5	333	211	0.63	2.55	12.74	2.51	7.74	12.99
261	5	336	239	0.71	2.55	10.80	2.52	5.80	11.09
262	5	331	230	0.69	1.63	11.10	1.61	6.10	11.22
263	5	331	239	0.72	1.46	9.09	1.45	4.09	9.21
264	5	333	177	0.53	4.18	13.61	4.11	8.62	14.23
265	5	333	225	0.68	2.18	12.11	2.15	7.11	12.30
266	5	331	218	0.66	3.81	13.54	3.75	8.55	14.06
267	5	331	223	0.67	3.10	10.74	3.06	5.75	11.17
268	5	340	230	0.68	2.01	11.07	1.98	6.07	11.25
269	5	331	239	0.72	2.18	9.94	2.16	4.94	10.17
270	5	331	230	0.69	1.82	10.87	1.80	5.87	11.02
271	5	333	211	0.63	2.55	12.08	2.51	7.08	12.34
272	5	331	184	0.56	3.63	12.89	3.57	7.90	13.38
273	5	333	264	0.79	-0.73	8.79	-0.72	3.79	8.82
274	5	331	222	0.67	4.17	10.26	4.12	5.27	11.07
275	5	333	218	0.65	3.08	14.22	3.02	9.23	14.54
276	5	331	195	0.59	3.27	13.45	3.22	8.46	13.83
277	5	333	211	0.63	2.91	11.30	2.87	6.31	11.66
278	5	338	200	0.59	4.91	12.56	4.83	7.58	13.47
279	5	335	264	0.79	0.36	6.92	0.36	1.92	6.93
280	5	340	197	0.58	3.44	12.22	3.39	7.23	12.69
281	5	333	179	0.54	6.52	13.43	6.41	8.46	14.90
282	5	336	195	0.58	2.72	14.82	2.67	9.83	15.06
283	5	331	257	0.78	1.82	6.23	1.81	1.23	6.49
284	5	331	243	0.73	0.90	10.99	0.89	5.99	11.03
285	5	331	190	0.57	1.09	16.18	1.07	11.18	16.22
286	5	338	241	0.71	1.28	11.22	1.26	6.22	11.29
287	5	340	243	0.71	1.09	10.02	1.08	5.02	10.08
288	5	335	250	0.75	2.37	9.82	2.34	4.82	10.10
289	5	336	202	0.60	4.36	15.33	4.27	10.34	15.92
290	5	331	204	0.62	2.91	12.98	2.86	7.99	13.30
291	5	336	218	0.65	1.46	14.05	1.43	9.05	14.12
292	5	331	244	0.74	2.37	9.06	2.35	4.06	9.36
293	5	327	213	0.65	-12.35	12.59	-12.16	7.70	17.57
294	5	329	223	0.68	1.27	11.94	1.25	6.94	12.01
295	5	333	206	0.62	2.36	13.29	2.32	8.29	13.49
296	5	329	267	0.81	0.92	5.17	0.92	0.17	5.25
297	5	332	200	0.60	3.27	12.37	3.22	7.38	12.79
298	5	331	239	0.72	2.01	14.09	1.97	9.09	14.23
299	5	329	202	0.61	3.27	13.89	3.21	8.90	14.26
300	5	331	241	0.73	-23.35	8.51	-23.14	3.92	24.77
301	5	333	229	0.69	-8.12	10.68	-8.02	5.73	13.39
302	5	335	203	0.61	2.36	13.19	2.32	8.19	13.40
303	5	329	216	0.66	3.63	10.08	3.59	5.09	10.71
304	5	331	213	0.64	4.00	12.51	3.94	7.52	13.12
305	5	331	220	0.66	12.00	11.24	11.84	6.35	16.39
306	5	331	234	0.71	2.73	7.58	2.71	2.59	8.05
307	5	333	169	0.51	4.72	14.90	4.63	9.92	15.61

Table 4. (cont)

308	5	336	186	0.55	3.63	14.82	3.56	9.83	15.25
309	5	333	232	0.70	1.63	10.79	1.61	5.79	10.91
310	5	327	177	0.54	5.44	14.02	5.34	9.04	15.02
311	5	331	248	0.75	1.28	8.11	1.27	3.11	8.21
312	5	333	160	0.48	4.55	15.30	4.46	10.32	15.95
313	5	333	191	0.57	2.18	12.71	2.15	7.71	12.89
314	5	333	229	0.69	1.46	12.80	1.44	7.80	12.88
315	5	335	239	0.71	2.55	10.93	2.52	5.93	11.22
316	5	332	235	0.71	2.91	11.31	2.87	6.32	11.67
317	5	332	230	0.69	3.27	11.20	3.23	6.21	11.66
318	5	336	239	0.71	2.18	11.29	2.15	6.29	11.50
319	5	336	243	0.72	1.82	9.92	1.80	4.92	10.08
320	5	331	244	0.74	1.82	8.70	1.80	3.70	8.89
321	5	335	262	0.78	-0.36	7.43	-0.36	2.43	7.44
322	5	329	239	0.73	1.27	8.91	1.26	3.91	9.00
323	5	333	147	0.44	7.07	15.66	6.93	10.70	17.15
324	5	331	209	0.63	3.63	12.08	3.58	7.09	12.61
325	5	338	183	0.54	4.36	15.63	4.27	10.64	16.21
326	5	331	225	0.68	2.36	12.85	2.32	7.85	13.06
327	5	333	244	0.73	1.09	10.17	1.08	5.17	10.23
328	5	335	236	0.70	2.73	10.96	2.69	5.97	11.29
329	5	329	163	0.50	4.89	13.88	4.80	8.90	14.70
330	5	327	239	0.73	2.91	7.41	2.89	2.42	7.96
331	5	335	211	0.63	2.91	13.18	2.86	8.19	13.49
332	5	329	222	0.67	1.99	12.27	1.96	7.27	12.43
333	5	333	183	0.55	3.63	15.07	3.56	10.08	15.49
334	5	331	244	0.74	0.73	8.76	0.72	3.76	8.79
335	5	338	220	0.65	2.37	10.34	2.34	5.34	10.61
336	5	327	216	0.66	1.82	12.75	1.79	7.75	12.88
337	5	331	197	0.60	18.60	13.19	18.30	8.45	22.67
338	5	333	216	0.65	2.18	11.77	2.15	6.77	11.97
339	5	336	237	0.71	1.46	12.22	1.44	7.22	12.31
340	5	335	239	0.71	2.18	12.09	2.15	7.09	12.28
341	5	333	230	0.69	2.37	11.63	2.34	6.63	11.87
342	5	331	230	0.69	1.27	10.98	1.25	5.98	11.05
343	5	335	248	0.74	1.64	10.08	1.62	5.08	10.21
344	5	331	197	0.60	4.00	13.23	3.93	8.24	13.81
345	5	338	253	0.75	0.92	9.70	0.91	4.70	9.74
346	5	335	225	0.67	2.91	13.60	2.86	8.61	13.90
347	5	333	243	0.73	1.46	10.91	1.44	5.91	11.01
348	5	331	230	0.69	1.46	10.77	1.44	5.77	10.87
487	10	327	40	0.12	8.67	24.83	8.14	14.94	26.21
488	10	327	32	0.10	6.35	23.17	6.00	13.23	23.98
489	10	329	123	0.37	5.44	20.56	5.18	10.60	21.24
490	10	334	60	0.18	7.41	22.77	7.01	12.85	23.88
491	10	330	96	0.29	9.02	22.51	8.54	12.63	24.16
492	10	332	64	0.19	9.02	22.04	8.55	12.16	23.73
493	10	330	80	0.24	8.31	19.60	7.94	9.70	21.22
494	10	327	100	0.31	7.95	21.67	7.54	11.76	23.02
495	10	329	143	0.44	5.99	20.96	5.70	11.01	21.76
496	10	327	48	0.15	8.67	23.51	8.18	13.62	24.97
497	10	326	48	0.15	7.41	20.32	7.06	10.40	21.58
498	10	327	64	0.20	11.14	23.67	10.50	13.85	26.02
499	10	332	64	0.19	10.27	22.33	9.72	12.48	24.47
500	10	330	32	0.10	9.73	27.16	9.06	17.29	28.73
501	10	332	39	0.12	8.12	21.74	7.70	11.83	23.14
502	10	332	84	0.25	11.49	21.98	10.89	12.17	24.67
503	10	330	22	0.07	9.73	22.15	9.22	12.29	24.09
504	10	334	36	0.11	7.24	23.20	6.84	13.27	24.24
505	10	332	92	0.28	9.37	20.65	8.92	10.78	22.59

Table 4. (cont)

506	10	334	40	0.12	9.02	25.12	8.46	15.24	26.59
507	10	329	96	0.29	8.84	19.56	8.45	9.67	21.39
508	10	324	16	0.05	7.95	25.74	7.44	15.83	26.86
509	10	334	36	0.11	10.43	28.57	9.66	18.72	30.26
510	10	332	20	0.06	8.31	25.84	7.77	15.94	27.06
511	10	330	20	0.06	7.95	24.00	7.49	14.09	25.21
512	10	327	48	0.15	12.00	20.97	11.41	11.18	24.03
513	10	327	40	0.12	14.59	20.83	13.88	11.14	25.24
514	10	332	48	0.15	7.78	25.27	7.29	15.36	26.37
515	10	334	100	0.30	7.60	19.97	7.25	10.05	21.31
516	10	342	80	0.23	9.02	21.56	8.56	11.68	23.29
517	10	350	56	0.16	10.95	21.95	10.38	12.12	24.41
518	10	347	28	0.08	1.82	23.89	1.71	13.89	23.96
519	10	338	38	0.11	4.36	25.09	4.09	15.12	25.44
521	10	350	72	0.21	6.69	23.98	6.30	14.04	24.84
522	10	349	96	0.28	5.44	21.88	5.16	11.92	22.51
524	10	337	33	0.10	5.08	23.98	4.78	14.02	24.48
525	10	334	52	0.16	11.14	16.66	10.74	6.84	19.95
526	10	334	44	0.13	11.14	23.29	10.51	13.47	25.68
527	10	337	32	0.10	16.28	19.83	15.54	10.21	25.45
528	10	337	24	0.07	5.80	24.00	5.46	14.05	24.65
529	10	330	39	0.12	7.60	24.05	7.15	14.13	25.15
530	10	331	28	0.09	10.79	24.50	10.14	14.67	26.64
531	10	327	38	0.12	15.61	22.18	14.79	12.53	26.89
532	10	326	29	0.09	9.02	23.81	8.50	13.93	25.37
533	10	325	29	0.09	9.02	23.81	8.50	13.93	25.37
534	10	334	133	0.40	6.88	19.91	6.57	9.98	21.02
535	10	330	181	0.55	6.33	14.01	6.16	4.07	15.35
536	10	328	33	0.10	8.67	20.47	8.26	10.58	22.16
539	10	333	52	0.16	10.08	22.93	9.53	13.08	24.94
540	10	330	57	0.17	7.60	23.98	7.16	14.06	25.09
541	10	327	38	0.12	-4.72	22.91	-4.46	12.94	23.37
542	10	331	24	0.07	5.44	22.77	5.14	12.81	23.38
544	10	329	38	0.12	-1.82	34.37	-1.65	24.37	34.41
545	10	326	45	0.14	8.31	25.22	7.79	15.32	26.47
547	10	321	62	0.19	9.73	17.12	9.37	7.26	19.62
548	10	329	29	0.09	9.37	22.27	8.87	12.40	24.07
549	10	333	95	0.29	9.73	18.52	9.33	8.66	20.84
550	10	327	95	0.29	4.00	18.02	3.84	8.04	18.44
551	10	329	67	0.20	12.18	21.70	11.56	11.91	24.74
552	10	329	33	0.10	6.88	25.37	6.45	15.44	26.23
554	10	335	104	0.31	9.02	24.00	8.49	14.12	25.54
555	10	331	139	0.42	5.44	22.34	5.15	12.38	22.96
556	10	333	36	0.11	12.88	22.98	12.17	13.22	26.17
557	10	334	107	0.32	8.67	21.17	8.24	11.28	22.80
558	10	334	52	0.16	9.37	22.48	8.87	12.61	24.26
559	10	333	80	0.24	6.52	23.90	6.14	13.96	24.72
560	10	327	159	0.49	4.72	17.06	4.55	7.09	17.68
561	10	334	36	0.11	7.24	25.04	6.79	15.11	26.00
563	10	330	87	0.26	6.88	20.86	6.55	10.93	21.92
564	10	332	•	•	5.80	19.45	5.54	9.50	20.26
565	10	332	68	0.21	9.73	24.33	9.15	14.46	26.09
566	10	334	84	0.25	12.88	23.74	12.14	13.98	26.83
567	10	329	40	0.12	7.95	24.23	7.48	14.32	25.43
568	10	331	52	0.16	7.24	23.06	6.84	13.13	24.11
569	10	334	111	0.33	8.31	19.10	7.95	9.20	20.77
570	10	329	56	0.17	10.08	25.43	9.44	15.57	27.23
571	10	328	131	0.40	7.24	20.31	6.90	10.39	21.51
572	10	330	127	0.39	3.63	19.86	3.47	9.88	20.18
574	10	330	68	0.21	11.14	22.57	10.54	12.75	25.04

Table 4. (cont)

575	10	329	44	0.13	9.02	23.65	8.50	13.77	25.22
578	10	328	64	0.20	9.37	22.89	8.86	13.02	24.64
579	10	329	100	0.30	7.60	21.44	7.22	11.52	22.69
581	10	329	153	0.47	5.08	18.02	4.88	8.06	18.70
582	10	333	115	0.35	9.73	21.58	9.24	11.72	23.58
583	10	327	25	0.08	5.44	24.00	5.12	14.04	24.57
584	10	332	84	0.25	7.95	21.84	7.54	11.93	23.18
585	10	334	33	0.10	6.16	23.83	5.80	13.88	24.57
587	10	328	72	0.22	9.02	24.02	8.49	14.14	25.56
589	10	330	151	0.46	5.80	18.13	5.57	8.18	19.01
590	10	331	60	0.18	7.60	22.89	7.18	12.97	24.05
591	10	328	32	0.10	9.37	26.62	8.74	16.74	28.11
592	10	327	30	0.09	9.02	25.61	8.45	15.73	27.05
593	10	329	25	0.08	1.09	22.90	1.03	12.90	22.92
594	10	325	32	0.10	10.43	22.78	9.86	12.94	24.94
349	15	331	55	0.17	2.55	32.65	2.25	17.66	32.74
350	15	329	23	0.07	5.25	27.66	4.77	12.72	28.12
351	15	326	•	•	13.39	32.18	11.86	17.54	34.58
352	15	326	45	0.14	26.79	28.60	24.19	15.04	38.40
354	15	336	30	0.09	7.07	29.36	6.36	14.46	30.13
357	15	326	23	0.07	11.65	32.71	10.29	17.98	34.50
358	15	332	•	•	-10.79	40.35	-9.10	25.57	41.53
359	15	327	56	0.17	13.57	27.47	12.33	12.85	30.40
360	15	326	34	0.10	4.00	25.10	3.68	10.13	25.40
361	15	331	•	•	3.63	24.64	3.35	9.67	24.89
362	15	327	27	0.08	12.53	32.96	11.05	18.27	35.01
366	15	326	23	0.07	10.08	31.56	8.96	16.76	32.97
367	15	326	27	0.08	9.37	31.76	8.32	16.94	32.97
368	15	326	•	•	17.61	30.49	15.75	16.11	34.78
370	15	332	26	0.08	11.67	33.90	10.24	19.17	35.62
371	15	324	•	•	7.42	30.48	6.64	15.59	31.29
374	15	326	•	•	8.31	27.41	7.55	12.55	28.55
375	15	326	24	0.07	9.73	32.75	8.59	17.94	34.01
377	15	329	•	•	16.95	28.70	15.30	14.28	32.96
382	15	331	26	0.08	-4.00	29.26	-3.60	14.29	29.51
385	15	331	24	0.07	13.40	27.07	12.20	12.44	29.98
390	15	331	27	0.08	9.02	28.73	8.14	13.90	30.00
397	15	332	81	0.24	12.88	31.77	11.44	17.10	34.03
398	15	335	142	0.42	11.32	32.44	10.01	17.70	34.15
399	15	330	128	0.39	17.28	30.25	15.47	15.85	34.43
400	15	328	113	0.34	7.95	31.34	7.08	16.47	32.23
402	15	•	•	•	14.43	30.35	12.91	15.77	33.31
403	15	330	57	0.17	13.91	32.85	12.28	18.23	35.37
404	15	325	37	0.11	11.65	32.23	10.32	17.50	34.06
408	15	329	81	0.25	13.91	32.26	12.32	17.65	34.83
410	15	328	80	0.24	9.73	31.32	8.66	16.51	32.65
414	15	329	80	0.24	5.61	28.43	5.07	13.49	28.93
417	15	324	84	0.26	5.08	27.07	4.63	12.12	27.51
418	15	327	82	0.25	9.73	32.37	8.61	17.56	33.65
419	15	326	82	0.25	7.95	32.01	7.05	17.14	32.88
421	15	329	91	0.28	9.37	28.35	8.47	13.53	29.74
422	15	329	80	0.24	6.52	30.38	5.83	15.47	31.01
423	15	330	79	0.24	10.43	31.73	9.26	16.95	33.23
425	15	323	85	0.26	9.90	29.89	8.88	15.09	31.34
426	15	327	80	0.24	14.59	31.80	12.95	17.23	34.67
432	15	332	82	0.25	4.72	30.64	4.22	15.68	30.97
435	15	335	•	•	10.08	32.07	8.94	17.27	33.45
436	15	328	23	0.07	11.84	28.46	10.70	13.75	30.63
438	15	329	72	0.22	14.93	25.44	13.71	10.90	29.24
443	15	332	•	•	8.85	32.73	7.82	17.89	33.78

Table 4. (cont)

445	15	330	•	•	26.64	28.58	24.06	15.01	38.29
448	15	326	25	0.08	12.00	29.38	10.79	14.67	31.53
450	15	328	28	0.09	16.95	31.72	15.05	17.29	35.54
451	15	323	20	0.06	14.25	27.89	12.92	13.30	31.06
457	15	326	29	0.09	13.22	30.24	11.84	15.59	32.75
458	15	329	29	0.09	8.31	27.58	7.55	12.72	28.71

Table 5. Ricochet test data, 9-mm, M882; at 25 m - sand

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
595.25	5	348	228	0.66	3.63	11.56	3.58	6.57	12.11
596.25	5	349	247	0.71	3.63	12.45	3.57	7.46	12.96
597.25	5	349	272	0.78	1.82	9.13	1.80	4.13	9.31
598.25	5	338	257	0.76	1.82	11.12	1.80	6.12	11.27
599.25	5	340	264	0.78	1.82	8.44	1.80	3.44	8.63
600.25	5	355	240	0.68	3.46	11.97	3.41	6.98	12.45
601.25	5	352	259	0.74	3.27	9.80	3.23	4.81	10.33
602.25	5	353	284	0.80	3.27	8.74	3.24	3.75	9.33
603.25	5	351	274	0.78	1.46	8.92	1.45	3.92	9.04
604.25	5	351	255	0.73	2.55	11.12	2.52	6.12	11.41
605.25	10	357	184	0.52	4.36	17.05	4.20	7.08	17.58
606.25	10	349	136	0.39	5.80	21.54	5.51	11.59	22.27
607.25	10	350	47	0.13	9.91	24.82	9.30	14.96	26.61
608.25	10	350	125	0.36	6.16	18.36	5.91	8.42	19.33
609.25	10	342	99	0.29	6.71	19.54	6.41	9.61	20.62
610.25	10	343	150	0.44	5.08	20.88	4.83	10.92	21.46
611.25	10	349	47	0.14	11.67	22.20	11.05	12.39	24.94
612.25	10	345	78	0.23	7.95	22.95	7.51	13.04	24.22
613.25	10	356	38	0.11	9.02	23.47	8.51	13.59	25.05
614.25	10	349	93	0.27	12.53	22.52	11.86	12.74	25.61
615.25	15	350	318	0.91	17.28	28.55	15.61	14.16	32.99
616.25	15	347	302	0.87	16.95	30.09	15.19	15.67	34.14
617.25	15	344	310	0.90	-12.53	25.80	-11.48	11.12	28.49
618.25	15	351	309	0.88	12.36	29.44	11.11	14.75	31.71
620.25	15	344	297	0.86	9.02	30.75	8.05	15.91	31.92
624.25	15	351	303	0.86	12.53	28.96	11.30	14.28	31.34

Table 6. Ricochet test data, 9-mm, M882; at 50 m - steel

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
113	5	333	307	0.92	0.00	7.66	0.00	2.66	7.66
114	5	335	316	0.94	0.36	7.24	0.36	2.24	7.25
115	5	329	313	0.95	0.36	7.08	0.36	2.08	7.09
116	5	329	300	0.91	0.36	7.31	0.36	2.31	7.32
117	5	330	306	0.93	0.00	6.35	0.00	1.35	6.35
120	5	332	302	0.91	0.55	6.53	0.55	1.53	6.55
121	5	327	304	0.93	0.73	5.91	0.73	0.91	5.95
122	5	329	308	0.94	0.36	6.91	0.36	1.91	6.92
123	5	328	313	0.95	0.18	6.64	0.18	1.64	6.64
125	5	328	310	0.95	0.36	7.35	0.36	2.35	7.36
126	5	333	315	0.95	0.00	7.46	0.00	2.46	7.46
127	5	329	310	0.94	0.18	6.93	0.18	1.93	6.93
128	5	327	322	0.98	0.36	6.48	0.36	1.48	6.49
130	5	333	•	•	0.36	6.48	0.36	1.48	6.49
131	5	327	322	0.98	0.73	7.19	0.72	2.19	7.23
132	5	330	322	0.98	0.36	6.67	0.36	1.67	6.68
134	5	328	319	0.97	0.73	7.48	0.72	2.48	7.52
135	5	330	308	0.93	0.73	6.67	0.73	1.67	6.71
136	5	334	312	0.93	-0.18	6.30	-0.18	1.30	6.30
137	5	329	303	0.92	0.18	6.26	0.18	1.26	6.26
141	5	326	312	0.96	0.36	6.65	0.36	1.65	6.66
142	5	330	315	0.95	-0.36	6.12	-0.36	1.12	6.13
144	5	326	305	0.94	3.63	6.92	3.61	1.93	7.81
145	5	326	306	0.94	0.00	6.25	0.00	1.25	6.25
147	5	324	320	0.99	0.18	6.59	0.18	1.59	6.59
148	5	332	319	0.96	0.36	6.11	0.36	1.11	6.12
150	5	328	312	0.95	0.90	6.89	0.89	1.89	6.95
151	5	325	304	0.94	0.00	6.04	0.00	1.04	6.04
152	5	330	305	0.92	0.19	7.05	0.19	2.05	7.05
160	5	325	310	0.95	0.17	7.00	0.17	2.00	7.00
161	5	327	320	0.98	-0.73	6.53	-0.73	1.53	6.57
162	5	329	307	0.93	0.00	6.00	0.00	1.00	6.00
163	5	329	308	0.94	0.17	6.12	0.17	1.12	6.12
164	5	328	308	0.94	0.36	6.34	0.36	1.34	6.35
166	5	331	311	0.94	-0.36	6.65	-0.36	1.65	6.66
169	5	324	305	0.94	-0.19	5.97	-0.19	0.97	5.97
170	5	329	306	0.93	0.17	7.51	0.17	2.51	7.51
173	5	325	304	0.94	0.00	6.41	0.00	1.41	6.41
177	5	332	308	0.93	0.36	6.51	0.36	1.51	6.52
178	5	329	310	0.94	-0.90	•	•	•	•
180	5	330	302	0.92	0.36	7.73	0.36	2.73	7.74
181	5	326	304	0.93	0.55	7.12	0.55	2.12	7.14
182	5	326	306	0.94	0.73	7.16	0.72	2.16	7.20
183	5	325	304	0.94	0.73	7.06	0.72	2.06	7.10
185	5	330	310	0.94	1.09	6.96	1.08	1.96	7.04
186	5	327	310	0.95	0.19	6.40	0.19	1.40	6.40
187	5	333	305	0.92	0.36	6.65	0.36	1.65	6.66
188	5	•	•	•	-1.46	6.12	-1.45	1.12	6.29
190	5	330	303	0.92	-0.36	6.77	-0.36	1.77	6.78
191	5	333	318	0.95	-0.36	6.77	-0.36	1.77	6.78
194	5	327	315	0.96	-0.73	7.01	-0.72	2.01	7.05
195	5	335	312	0.93	0.00	8.72	0.00	3.72	8.72
196	5	332	305	0.92	-1.46	7.19	-1.45	2.19	7.34
197	5	321	307	0.96	-1.82	6.78	-1.81	1.78	7.02
199	5	327	320	0.98	-1.09	5.08	-1.09	0.08	5.20

Table 6. (cont)

201	5	327	310	0.95	-1.46	6.05	-1.45	1.05	6.22
202	5	336	317	0.94	-0.36	6.99	-0.36	1.99	7.00
204	5	328	317	0.97	-1.46	7.95	-1.45	2.95	8.08
205	5	330	318	0.96	-1.09	6.55	-1.08	1.55	6.64
207	5	333	316	0.95	-1.82	7.37	-1.81	2.37	7.59
208	5	333	305	0.92	-0.36	6.90	-0.36	1.90	6.91
210	5	335	317	0.95	-0.19	7.32	-0.19	2.32	7.32
211	5	324	312	0.96	-1.09	6.91	-1.08	1.91	7.00
212	5	•	•	•	-1.09	7.07	-1.08	2.07	7.15
213	5	335	308	0.92	-1.09	7.02	-1.08	2.02	7.10
215	5	329	308	0.94	-1.09	6.40	-1.08	1.40	6.49
216	5	331	303	0.92	-1.09	6.35	-1.08	1.35	6.44
218	5	333	301	0.9	-1.09	6.15	-1.08	1.15	6.25
219	5	331	300	0.91	-1.09	6.48	-1.08	1.48	6.57
220	5	331	303	0.92	-1.09	6.96	-1.08	1.96	7.04
221	5	336	320	0.95	-1.09	7.47	-1.08	2.47	7.55
222	5	331	322	0.97	-0.73	6.35	-0.73	1.35	6.39
223	5	333	308	0.92	-0.73	6.91	-0.73	1.91	6.95
224	5	331	305	0.92	-0.92	6.35	-0.91	1.35	6.42
225	5	334	308	0.92	-1.25	6.14	-1.24	1.14	6.27
226	5	331	315	0.95	-1.46	5.92	-1.45	0.92	6.10
227	5	323	306	0.95	-0.73	6.53	-0.73	1.53	6.57
228	5	332	319	0.96	-1.09	6.72	-1.08	1.72	6.81
229	5	329	305	0.93	-1.27	6.69	-1.26	1.69	6.81
230	5	328	304	0.93	-1.46	6.69	-1.45	1.69	6.85
231	5	329	306	0.93	-1.09	6.46	-1.08	1.46	6.55
232	5	324	310	0.96	-1.09	6.78	-1.08	1.78	6.87
233	5	323	320	0.99	-1.09	6.89	-1.08	1.89	6.98
234	5	331	309	0.93	-1.09	7.09	-1.08	2.09	7.17
235	5	320	313	0.98	-2.18	6.40	-2.17	1.40	6.76
236	5	328	316	0.96	-1.09	8.01	-1.08	3.01	8.08
237	5	320	307	0.96	-1.82	6.72	-1.81	1.72	6.96
238	5	329	321	0.98	-1.09	6.19	-1.08	1.19	6.28
239	5	331	324	0.98	-1.09	6.92	-1.08	1.92	7.00
240	5	331	318	0.96	-0.36	6.02	-0.36	1.02	6.03
241	5	328	306	0.93	-0.73	6.96	-0.73	1.96	7.00
242	5	327	322	0.98	2.18	6.93	2.17	1.93	7.26
243	5	329	306	0.93	-0.73	7.30	-0.72	2.30	7.34
244	5	327	320	0.98	-0.36	7.03	-0.36	2.03	7.04
245	5	329	303	0.92	-1.46	7.02	-1.45	2.02	7.17
246	5	324	310	0.96	-0.73	6.97	-0.73	1.97	7.01
247	5	327	306	0.94	-1.09	6.65	-1.08	1.65	6.74
248	5	330	302	0.92	-1.82	6.76	-1.81	1.76	7.00
3	10	331	321	0.97	0.00	11.18	0.00	1.18	11.18
5	10	329	320	0.973	1.09	10.95	1.07	0.95	11.00
6	10	•	•	•	1.09	10.78	1.07	0.78	10.83
7	10	332	324	0.976	1.09	11.05	1.07	1.05	11.10
8	10	325	317	0.975	1.09	11.03	1.07	1.03	11.08
9	10	327	319	0.976	1.46	15.99	1.41	5.99	16.05
10	10	326	318	0.975	1.82	11.18	1.79	1.18	11.33
11	10	330	318	0.964	1.09	11.65	1.07	1.65	11.70
12	10	328	321	0.979	0.36	11.64	0.35	1.64	11.65
14	10	328	320	0.976	-1.46	11.83	-1.43	1.83	11.92
15	10	325	316	0.972	0.00	10.47	0.00	0.47	10.47
16	10	•	•	•	0.36	10.84	0.35	0.84	10.85
17	10	328	312	0.951	1.46	10.51	1.44	0.51	10.61

Table 6. (cont)

18	10	326	318	0.975	1.46	10.97	1.43	0.97	11.07
19	10	327	311	0.951	0.73	10.78	0.72	0.78	10.80
20	10	328	303	0.924	-0.73	11.77	-0.71	1.77	11.79
21	10	327	312	0.954	0.36	11.26	0.35	1.26	11.27
23	10	326	307	0.942	0.73	12.30	0.71	2.30	12.32
24	10	325	293	0.902	1.09	10.78	1.07	0.78	10.83
25	10	328	305	0.93	0.73	10.78	0.72	0.78	10.80
26	10	330	307	0.93	0.00	10.17	0.00	0.17	10.17
27	10	324	302	0.932	1.09	10.90	1.07	0.90	10.95
28	10	325	305	0.938	1.09	10.99	1.07	0.99	11.04
29	10	330	313	0.948	1.46	11.64	1.43	1.64	11.73
30	10	327	305	0.933	1.46	10.46	1.44	0.46	10.56
31	10	325	303	0.932	1.09	10.96	1.07	0.96	11.01
32	10	324	305	0.941	0.73	10.38	0.72	0.38	10.41
33	10	323	302	0.935	1.09	10.78	1.07	0.78	10.83
34	10	323	297	0.92	0.73	10.59	0.72	0.59	10.61
36	10	323	307	0.95	1.46	•	•	•	•
37	10	326	311	0.954	0.73	•	•	•	•
38	10	324	307	0.948	1.09	11.33	1.07	1.33	11.38
39	10	326	312	0.957	1.09	10.35	1.07	0.35	10.41
40	10	331	310	0.937	-0.36	10.10	-0.35	0.10	10.11
41	10	331	307	0.927	-0.36	10.68	-0.35	0.68	10.69
42	10	336	313	0.932	-0.36	10.37	-0.35	0.37	10.38
43	10	327	307	0.939	0.36	10.80	0.35	0.80	10.81
44	10	324	301	0.929	-0.73	11.43	-0.72	1.43	11.45
45	10	329	308	0.936	-0.17	10.42	-0.17	0.42	10.42
46	10	330	313	0.948	-0.48	10.95	-0.47	0.95	10.96
47	10	333	311	0.934	0.00	10.38	0.00	0.38	10.38
48	10	329	306	0.93	-0.73	11.42	-0.72	1.42	11.44
49	10	327	309	0.945	0.00	10.80	0.00	0.80	10.80
50	10	334	318	0.952	-0.17	11.60	-0.17	1.60	11.60
52	10	329	306	0.93	-0.36	10.54	-0.35	0.54	10.55
53	10	322	309	0.96	0.00	11.07	0.00	1.07	11.07
54	10	331	310	0.937	-0.73	10.05	-0.72	0.05	10.08
55	10	329	308	0.936	-0.36	10.37	-0.35	0.37	10.38
56	10	332	315	0.949	-0.36	10.37	-0.35	0.37	10.38
57	10	329	306	0.93	-0.36	10.97	-0.35	0.97	10.98
58	10	329	308	0.936	-0.36	10.80	-0.35	0.80	10.81
59	10	331	308	0.931	-0.36	10.07	-0.35	0.07	10.08
60	10	330	311	0.942	0.92	10.51	0.90	0.51	10.55
61	10	327	306	0.936	-0.92	11.85	-0.90	1.85	11.89
62	10	327	308	0.942	-0.36	11.14	-0.35	1.14	11.15
63	10	329	307	0.933	-0.73	10.36	-0.72	0.36	10.39
64	10	329	308	0.936	-0.36	11.83	-0.35	1.83	11.84
65	10	330	299	0.906	0.00	10.32	0.00	0.32	10.32
66	10	326	303	0.929	-0.36	10.40	-0.35	0.40	10.41
68	10	331	298	0.9	-0.19	10.55	-0.19	0.55	10.55
69	10	325	301	0.926	-0.36	10.81	-0.35	0.81	10.82
70	10	330	315	0.955	0.00	11.21	0.00	1.21	11.21
71	10	327	310	0.948	-0.36	10.06	-0.35	0.06	10.07
72	10	330	305	0.924	0.36	10.84	0.35	0.84	10.85
74	10	327	305	0.933	-0.73	11.51	-0.72	1.51	11.53
75	10	331	309	0.934	0.00	10.43	0.00	0.43	10.43
77	10	328	312	0.951	-0.73	10.74	-0.72	0.74	10.76
78	10	330	324	0.982	-0.36	11.14	-0.35	1.14	11.15
78	10	•	•	•	0.00	10.13	0.00	0.13	10.13

Table 6. (cont)

81	10	325	305	0.938	-0.36	11.46	-0.35	1.46	11.47
82	10	327	308	0.942	-0.73	10.66	-0.72	0.66	10.68
83	10	327	310	0.948	-0.73	11.14	-0.72	1.14	11.16
84	10	329	312	0.948	-0.36	10.62	-0.35	0.62	10.63
85	10	330	315	0.955	-0.73	10.27	-0.72	0.27	10.30
86	10	327	311	0.951	0.00	11.09	0.00	1.09	11.09
87	10	331	314	0.949	-0.36	11.10	-0.35	1.10	11.11
88	10	326	305	0.936	-0.36	10.85	-0.35	0.85	10.86
89	10	329	303	0.921	-0.54	10.49	-0.53	0.49	10.50
90	10	329	312	0.948	-1.46	10.41	-1.44	0.41	10.51
91	10	327	310	0.948	-0.36	11.17	-0.35	1.17	11.18
92	10	327	304	0.93	0.73	10.33	0.72	0.33	10.36
93	10	331	307	0.927	-0.36	11.20	-0.35	1.20	11.21
94	10	329	307	0.933	-0.36	11.05	-0.35	1.05	11.06
95	10	327	310	0.948	-1.82	10.86	-1.79	0.86	11.01
96	10	329	307	0.933	0.00	10.79	0.00	0.79	10.79
97	10	327	311	0.951	0.92	11.01	0.90	1.01	11.05
98	10	330	314	0.952	-0.36	11.10	-0.35	1.10	11.11
99	10	330	306	0.927	-0.73	11.78	-0.71	1.78	11.80
100	10	329	313	0.951	0.90	11.38	0.88	1.38	11.42
101	10	329	311	0.945	-0.36	11.49	-0.35	1.49	11.50
102	10	333	315	0.946	0.00	10.86	0.00	0.86	10.86
103	10	325	311	0.957	-0.36	11.70	-0.35	1.70	11.71
104	10	324	305	0.941	0.00	11.02	0.00	1.02	11.02
105	10	328	304	0.927	0.00	11.10	0.00	1.10	11.10
106	10	326	310	0.951	0.36	10.58	0.35	0.58	10.59
107	10	325	298	0.917	-0.36	10.29	-0.35	0.29	10.30
108	10	327	306	0.936	-0.36	•	•	•	•
109	10	324	298	0.92	-0.36	10.51	-0.35	0.51	10.52
110	10	327	310	0.948	-0.17	11.02	-0.17	1.02	11.02
112	10	328	312	0.951	0.36	10.79	0.35	0.79	10.80
111	10	327	306	0.936	0.00	10.33	0.00	0.33	10.33
595	15	349	318	0.91	-0.36	16.80	-0.34	1.80	16.80
596	15	351	302	0.86	0.00	17.57	0.00	2.57	17.57
597	15	346	310	0.9	-0.36	17.78	-0.34	2.78	17.78
598	15	341	308	0.9	-0.36	17.96	-0.34	2.96	17.96
599	15	345	314	0.91	-0.36	17.39	-0.34	2.39	17.39
600	15	344	312	0.91	-0.92	17.00	-0.88	2.00	17.02
601	15	339	300	0.88	-0.19	17.41	-0.18	2.41	17.41
602	15	345	314	0.91	0.00	16.82	0.00	1.82	16.82
603	15	342	312	0.91	0.36	16.27	0.35	1.27	16.27
604	15	345	315	0.91	0.54	16.39	0.52	1.39	16.40
605	15	346	311	0.9	-0.36	17.31	-0.34	2.31	17.31
606	15	345	315	0.91	0.73	17.03	0.70	2.03	17.05
607	15	341	316	0.93	0.36	16.63	0.35	1.63	16.63
608	15	340	311	0.91	1.09	17.21	1.04	2.21	17.24
609	15	345	310	0.9	-0.36	17.19	-0.34	2.19	17.19
610	15	336	307	0.91	-0.73	16.32	-0.70	1.32	16.34
611	15	341	311	0.91	0.36	16.30	0.35	1.30	16.30
612	15	337	304	0.9	1.16	17.18	1.11	2.18	17.22
613	15	353	313	0.89	-0.36	17.79	-0.34	2.79	17.79
614	15	338	307	0.91	0.36	18.01	0.34	3.01	18.01
615	15	349	310	0.89	-0.36	18.99	-0.34	3.99	18.99
616	15	346	313	0.9	0.36	17.28	0.34	2.28	17.28
617	15	350	307	0.88	0.00	17.42	0.00	2.42	17.42
618	15	345	308	0.89	-0.19	17.36	-0.18	2.36	17.36

Table 6. (cont)

619	15	344	309	0.9	0.00	17.42	0.00	2.42	17.42
620	20	344	297	0.86	0.36	20.80	0.34	0.80	20.80
621	20	343	294	0.86	0.36	20.54	0.34	0.54	20.54
622	20	347	291	0.84	-1.46	22.73	-1.35	2.74	22.77
623	20	340	290	0.85	1.09	21.96	1.01	1.96	21.99
624	20	347	295	0.85	0.17	22.74	0.16	2.74	22.74
625	20	347	298	0.86	0.36	22.43	0.33	2.43	22.43
626	20	341	281	0.82	-4.00	21.91	-3.71	1.95	22.25
627	20	337	287	0.85	0.73	22.74	0.67	2.74	22.75
628	20	342	285	0.83	1.09	22.11	1.01	2.11	22.14
629	20	347	288	0.83	-1.82	23.34	-1.67	3.35	23.41
630	20	342	289	0.85	0.54	22.43	0.50	2.43	22.44
631	20	341	289	0.85	-0.36	24.87	-0.33	4.87	24.87
632	20	342	284	0.83	-0.73	22.50	-0.68	2.50	22.51
633	20	337	285	0.85	1.46	21.80	1.36	1.81	21.85
634	20	338	292	0.86	0.73	21.49	0.68	1.49	21.50
645	25	335	266	0.79	4.00	28.66	3.52	3.71	28.91
646	25	336	259	0.77	3.63	26.78	3.24	1.82	27.01
647	25	336	269	0.8	1.27	32.10	1.08	7.11	32.12
648	25	336	266	0.79	2.55	29.52	2.23	4.54	29.62
649	25	332	263	0.79	-4.36	32.62	-3.70	7.68	32.88
650	25	334	266	0.8	1.99	29.34	1.74	4.35	29.40
651	25	337	271	0.8	9.20	27.92	8.13	3.20	29.28
652	25	341	267	0.78	5.98	32.94	5.07	8.05	33.42
653	25	342	273	0.8	5.62	28.12	4.96	3.22	28.63
654	25	333	271	0.81	3.27	28.92	2.87	3.95	29.09
655	25	339	269	0.79	2.55	29.01	2.24	4.03	29.11
656	25	339	276	0.81	1.09	28.99	0.96	3.99	29.01
657	25	333	262	0.79	2.36	29.22	2.07	4.24	29.31
658	25	337	275	0.82	3.27	29.42	2.86	4.45	29.59
659	25	339	269	0.79	1.82	29.43	1.59	4.44	29.48
660	25	339	271	0.8	2.91	28.75	2.56	3.78	28.88
661	25	341	276	0.81	-0.36	29.65	-0.31	4.65	29.65
662	25	348	286	0.82	-1.46	30.14	-1.27	5.15	30.17
663	25	337	264	0.78	2.91	29.43	2.54	4.46	29.56
664	25	337	271	0.8	2.00	29.04	1.75	4.05	29.10
665	25	338	260	0.77	0.00	29.71	0.00	4.71	29.71
666	25	332	266	0.8	1.64	29.61	1.43	4.62	29.65
667	25	336	271	0.81	2.73	29.14	2.39	4.16	29.26
668	25	339	269	0.79	1.82	29.79	1.58	4.80	29.84
669	25	340	265	0.78	3.09	29.48	2.70	4.51	29.63

Table 7. Ricochet test data, 9-mm, M882; at 25 m - steel

Round No.	Impact Angle	Vi(m/s)	Vr(m/s)	Vr/Vi	Azi/E	Elev/E	Azi/R	Elev/R	Beta
670.25	5	348	340	0.98	-2.18	5.80	-2.17	0.80	6.19
671.25	5	354	338	0.95	-2.55	6.25	-2.54	1.25	6.75
672.25	5	339	329	0.97	6.70	5.10	6.67	0.13	8.41
673.25	5	348	339	0.97	-1.82	6.89	-1.81	1.89	7.13
674.25	5	341	327	0.96	-1.64	6.75	-1.63	1.75	6.95
675.25	5	346	334	0.97	-2.55	5.83	-2.54	0.83	6.36
676.25	5	344	329	0.96	-1.82	6.70	-1.81	1.70	6.94
677.25	5	346	336	0.97	-2.18	6.50	-2.17	1.50	6.85
678.25	5	344	333	0.97	-1.82	7.15	-1.81	2.15	7.38
679.25	5	343	328	0.96	-2.18	6.40	-2.17	1.40	6.76
680.25	5	344	330	0.96	-1.82	6.43	-1.81	1.43	6.68
681.25	5	349	328	0.94	-1.82	7.21	-1.81	2.21	7.43
682.25	5	342	328	0.96	-1.82	6.89	-1.81	1.89	7.13
683.25	5	345	332	0.96	-1.46	6.65	-1.45	1.65	6.81
684.25	5	349	332	0.95	-2.18	6.47	-2.17	1.47	6.83
685.25	5	340	327	0.96	-2.91	5.96	-2.89	0.97	6.63
686.25	5	345	330	0.96	-2.91	5.83	-2.90	0.84	6.51
687.25	5	344	327	0.95	-2.18	6.91	-2.17	1.91	7.24
688.25	5	341	326	0.96	-1.46	5.98	-1.45	0.98	6.16
689.25	5	346	331	0.96	-1.82	6.24	-1.81	1.24	6.50
690.25	5	348	335	0.96	-2.18	6.90	-2.17	1.90	7.23
691.25	5	346	334	0.97	-1.64	6.36	-1.63	1.36	6.57
692.25	5	350	338	0.97	-2.55	7.52	-2.53	2.52	7.94
693.25	5	340	327	0.96	-1.46	6.90	-1.45	1.90	7.05
694.25	5	350	334	0.95	-2.55	5.74	-2.54	0.74	6.28
695.25	10	340	323	0.95	-1.82	11.47	-1.78	1.47	11.61
696.25	10	339	330	0.973	-1.82	11.30	-1.79	1.30	11.44
697.25	10	341	332	0.974	-1.46	10.88	-1.43	0.88	10.98
698.25	10	335	325	0.97	-2.55	12.08	-2.50	2.09	12.34
699.25	10	334	324	0.97	-3.10	11.61	-3.04	1.62	12.01
700.25	10	340	332	0.976	-2.18	11.94	-2.13	1.95	10.22
701.25	10	338	332	0.982	-1.82	12.05	-1.78	2.05	12.18
702.25	10	334	327	0.979	-2.91	11.82	-2.85	1.83	12.17
703.25	10	343	325	0.948	-2.18	11.79	-2.14	1.80	11.99
704.25	10	339	333	0.982	-2.18	11.42	-2.14	1.43	11.62
705.25	10	337	321	0.953	-2.18	11.88	-2.13	1.89	12.08
706.25	10	337	315	0.935	-2.55	11.42	-2.50	1.43	11.70
707.25	10	341	334	0.979	-2.37	11.58	-2.32	1.59	11.82
708.25	10	343	326	0.95	-2.55	12.07	-2.50	2.08	12.33
709.25	10	336	320	0.952	-1.46	10.68	-1.43	0.68	10.78
710.25	10	341	324	0.95	-2.18	11.43	-2.14	1.44	11.63
711.25	10	343	326	0.95	-2.55	11.07	-2.50	1.08	11.36
712.25	10	341	323	0.947	-2.01	12.68	-1.96	2.69	12.84
713.25	10	346	329	0.951	-2.55	11.27	-2.50	1.28	11.55
714.25	10	340	322	0.947	-2.37	12.43	-2.32	2.44	12.65
715.25	10	345	320	0.928	4.00	11.05	3.93	1.07	11.74
716.25	10	341	324	0.95	-2.73	11.63	-2.68	1.64	11.94
717.25	10	345	323	0.936	-2.37	11.44	-2.32	1.45	11.68
718.25	10	341	325	0.953	-1.82	11.31	-1.79	1.31	11.45
719.25	10	346	331	0.957	-1.82	11.29	-1.79	1.29	11.43
635.25	20	355	301	0.85	-1.99	22.26	-1.84	2.27	22.34
636.25	20	346	300	0.87	-1.27	21.01	-1.19	1.01	21.05
637.25	20	348	311	0.89	-1.09	21.49	-1.01	1.49	21.52
638.25	20	340	293	0.86	0.00	20.54	0.00	0.54	20.54
639.25	20	343	295	0.86	-1.09	23.20	-1.00	3.20	23.22

Table 7. (cont)

640.25	20	344	302	0.88	-6.88	21.97	-6.38	2.10	22.97
641.25	20	344	300	0.87	-0.36	20.54	-0.34	0.54	20.54
642.25	20	346	302	0.87	-0.73	20.22	-0.69	0.22	20.23
643.25	20	346	312	0.9	0.00	•	•	•	•
644.25	20	347	302	0.87	-1.46	21.64	-1.36	1.65	21.69

Table 8. Statistics for ricochet test data, .50-caliber, M33 - sand

X_1: Vr/Vi

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.57	.21	.01	.04	36.7	252
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.03	.95	.92	144.36	93.8	115

X_2: Azimuth/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
6.48	10.18	.55	103.7	157.13	338
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-31.23	47.75	78.98	2190.52	49141.68	29

X_3: Elevation/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
29.97	13.05	.71	170.34	43.55	337
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
6.18	65.9	59.72	10099.27	359891.74	30

X_4: Azimuth/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
5.81	8.62	.47	74.28	148.44	337
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-25.67	44.45	70.12	1956.58	36316.19	30

X_5: Elevation/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
20.65	9.84	.54	96.8	47.64	337
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
1.19	51.12	49.93	6960.02	176270.52	30

X_6: Beta

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
31.74	14.15	.77	200.34	44.6	337
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
7.16	66.47	59.31	10694.81	406717.28	30

Table 9. Statistics for ricochet test data, .50-caliber - steel

X_1: Vr/Vi

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.89	.08	4.89E-3	.01	9.04	269
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.61	.99	.38	238.85	213.8	11

X_2: Azi/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.63	3.08	.19	9.48	490.89	277
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-10.73	19.74	30.47	173.77	2726.36	3

X_3: Elev/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
22.87	15.07	.91	227.07	65.89	276
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.29	69.2	63.91	6312.11	206802.24	4

X_4: Azi/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.5	2.43	.15	5.91	490.26	276
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-7	15.43	22.43	136.91	1694.33	4

X_5: Elev/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
4.49	4.12	.25	17.01	91.84	276
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.29	20.23	19.94	1239.57	10245.74	4

X_6: Beta

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
23.04	15.08	.91	227.26	65.43	276
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.45	69.3	63.85	6359.4	209024.92	4

Table 10. Statistics for ricochet test data, 9-mm, M882 - sand

X_1: Vr/Vi

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.41	.26	.02	.07	63.87	259
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.05	.91	.86	106.38	61.45	12

X_2: Azi/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
6.25	5.4	.33	29.21	86.5	271
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-23.35	26.79	50.14	1693.22	18465.32	0

X_3: Elev/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
19.67	7.67	.47	58.78	38.98	271
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.17	40.35	35.18	5330.77	120731.05	0

X_4: Azi/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
5.84	4.97	.3	24.68	85.05	271
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-23.14	24.19	47.33	1583.15	15913.47	0

X_5: Elev/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
10.76	4.36	.26	19.02	40.53	271
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.17	25.57	25.4	2915.7	36504.45	0

X_6: Beta

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
20.98	8.33	.51	69.31	39.69	271
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.25	41.53	36.28	5684.58	137954.3	0

Table 11. Statistics for ricochet test data, 9-mm, M882 - steel

X_1: Vr/Vi

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.92	.05	2.76E-3	2.42E-3	5.32	318
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.77	.99	.22	293.87	272.34	6

X_2: Azi/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
-.23	1.59	.09	2.51	-681.28	324
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-6.88	9.2	16.08	-75.38	829.01	0

X_3: Elev/E

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
12.14	6.74	.38	45.42	55.5	319
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.08	32.94	27.86	3873.95	61490.34	5

X_4: Azi/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
-.25	1.5	.08	2.24	-589.62	319
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
-6.38	8.13	14.51	-80.97	732.8	5

X_5: Elev/R

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
1.74	1.17	.07	1.37	67.31	319
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
.05	8.05	8	555.36	1403.55	5

X_6: Beta

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
12.24	6.74	.38	45.4	55.04	319
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum of Sqr.:**	**# Missing:**
5.2	33.42	28.22	3904.93	62238.13	5

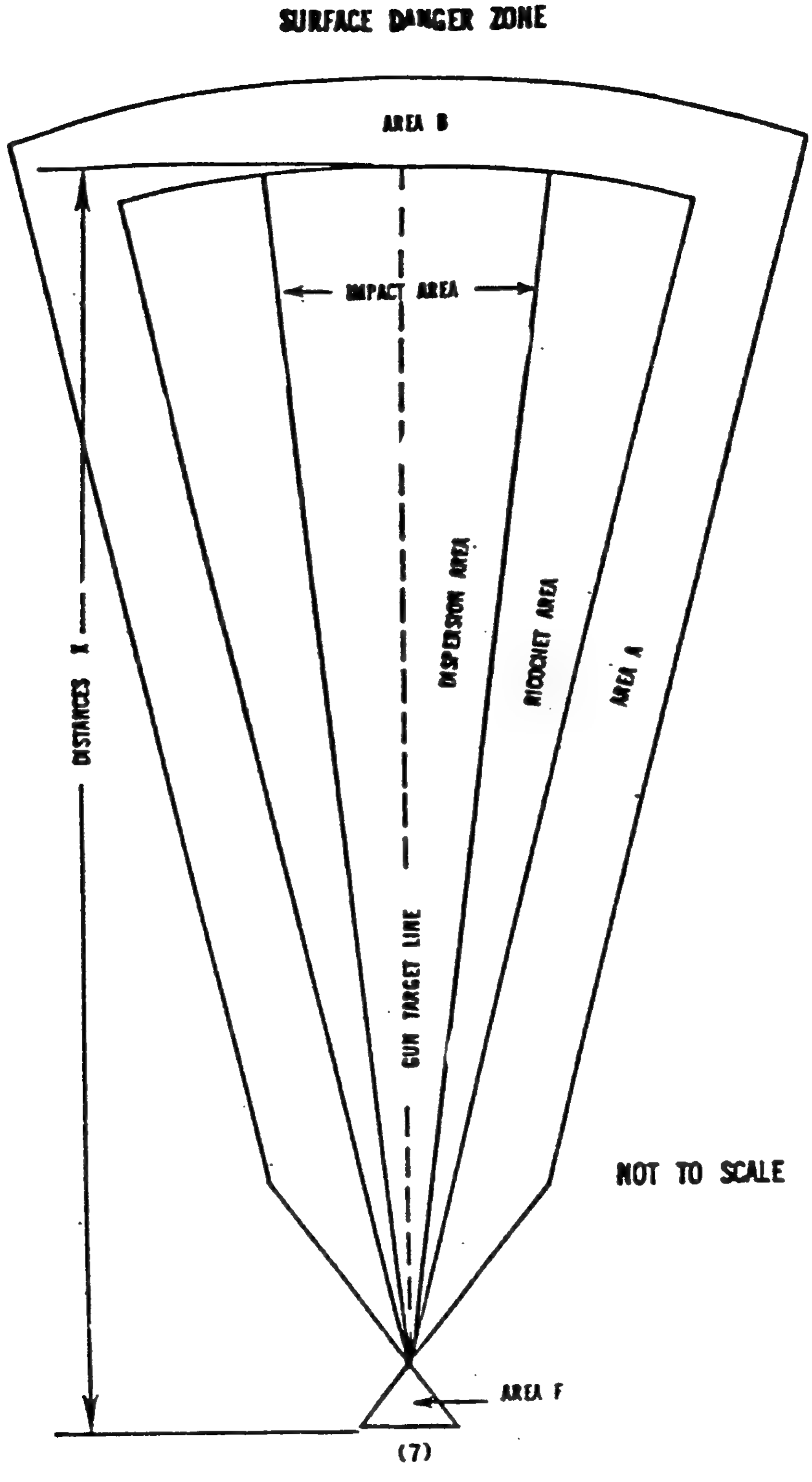


Figure 1. Sample SDZ - direct fire mode

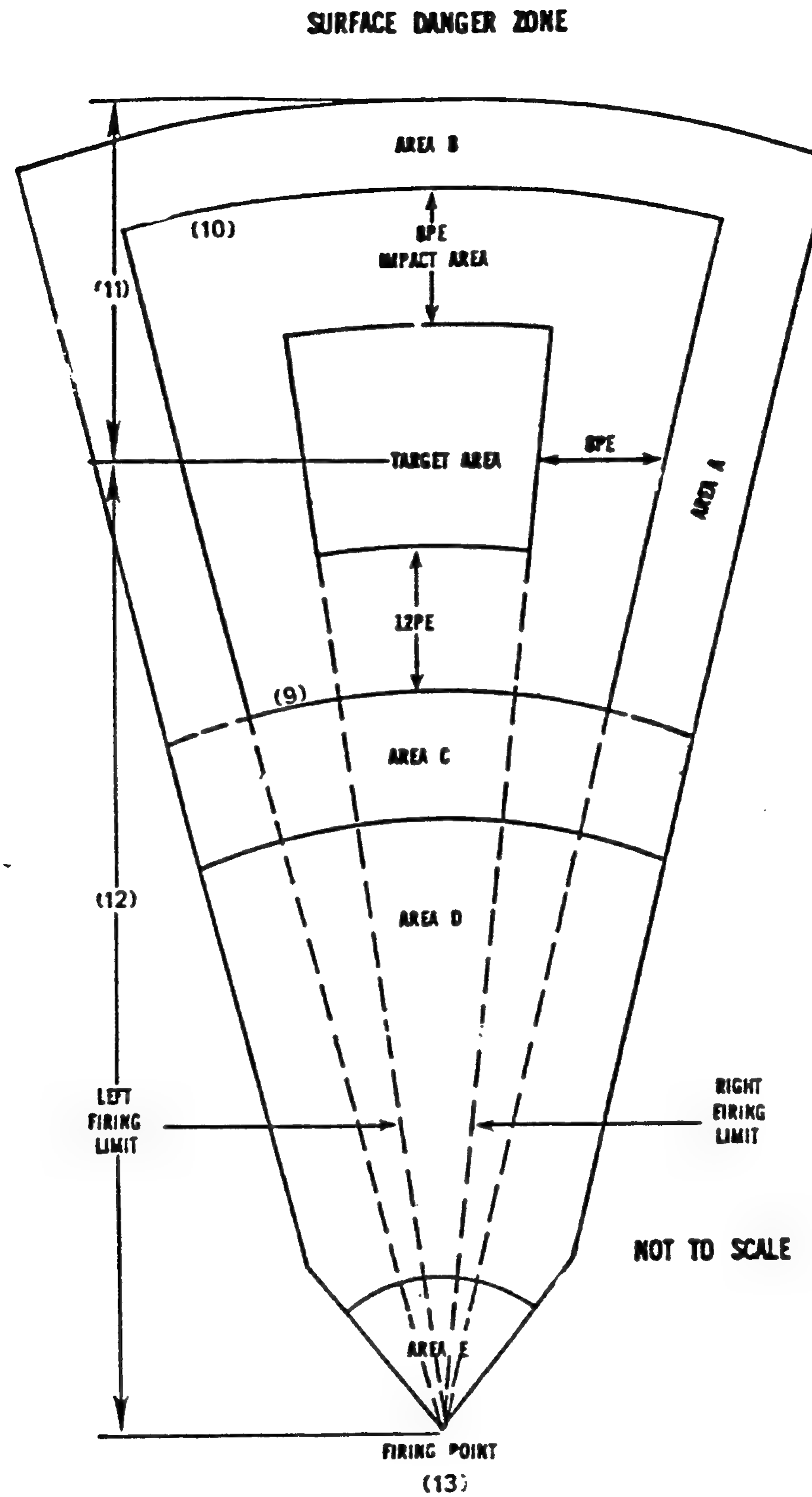


Figure 2. Sample SDZ - indirect fire mode

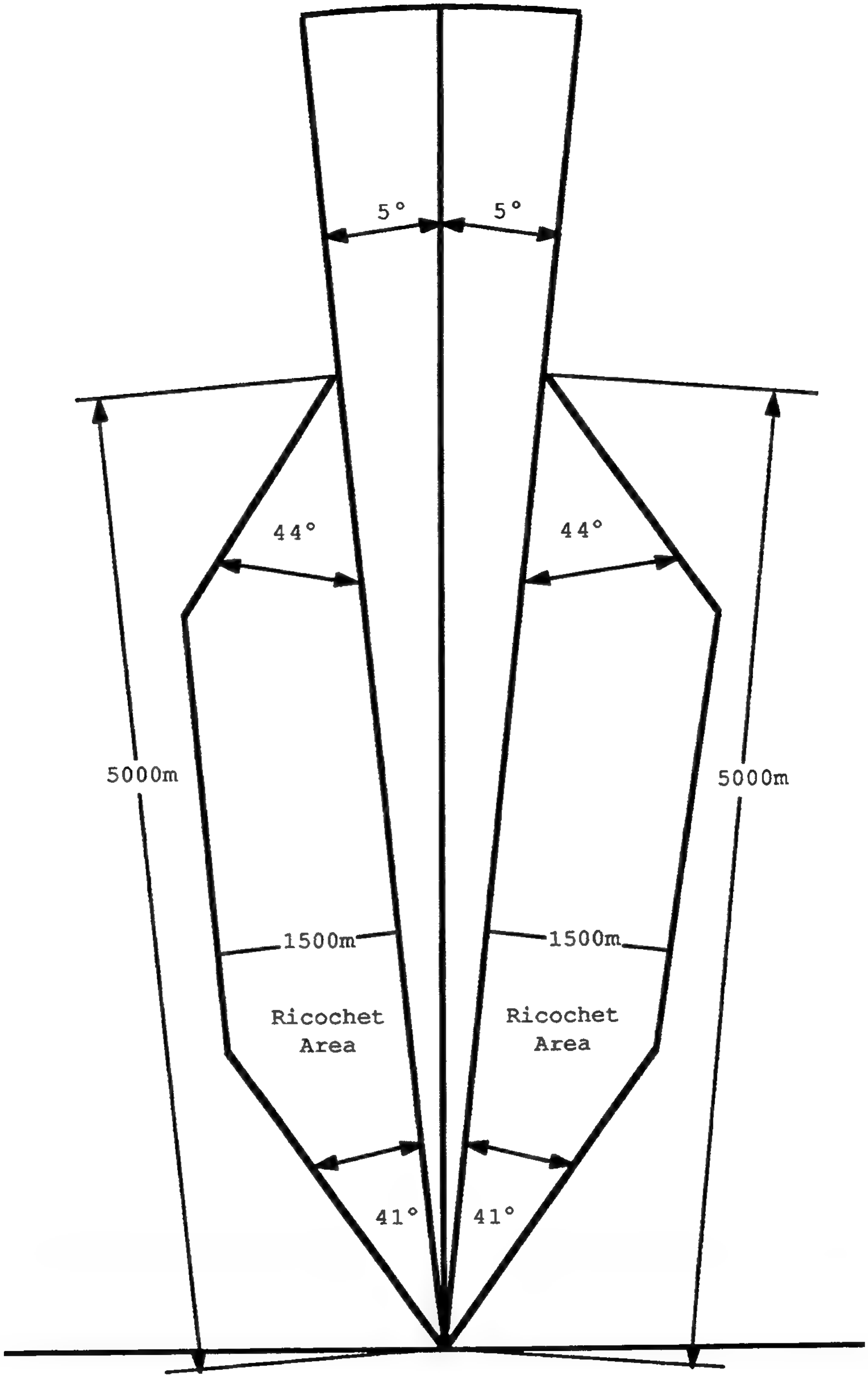


Figure 3. SDZ - .50-caliber, Ball; M2 and M33

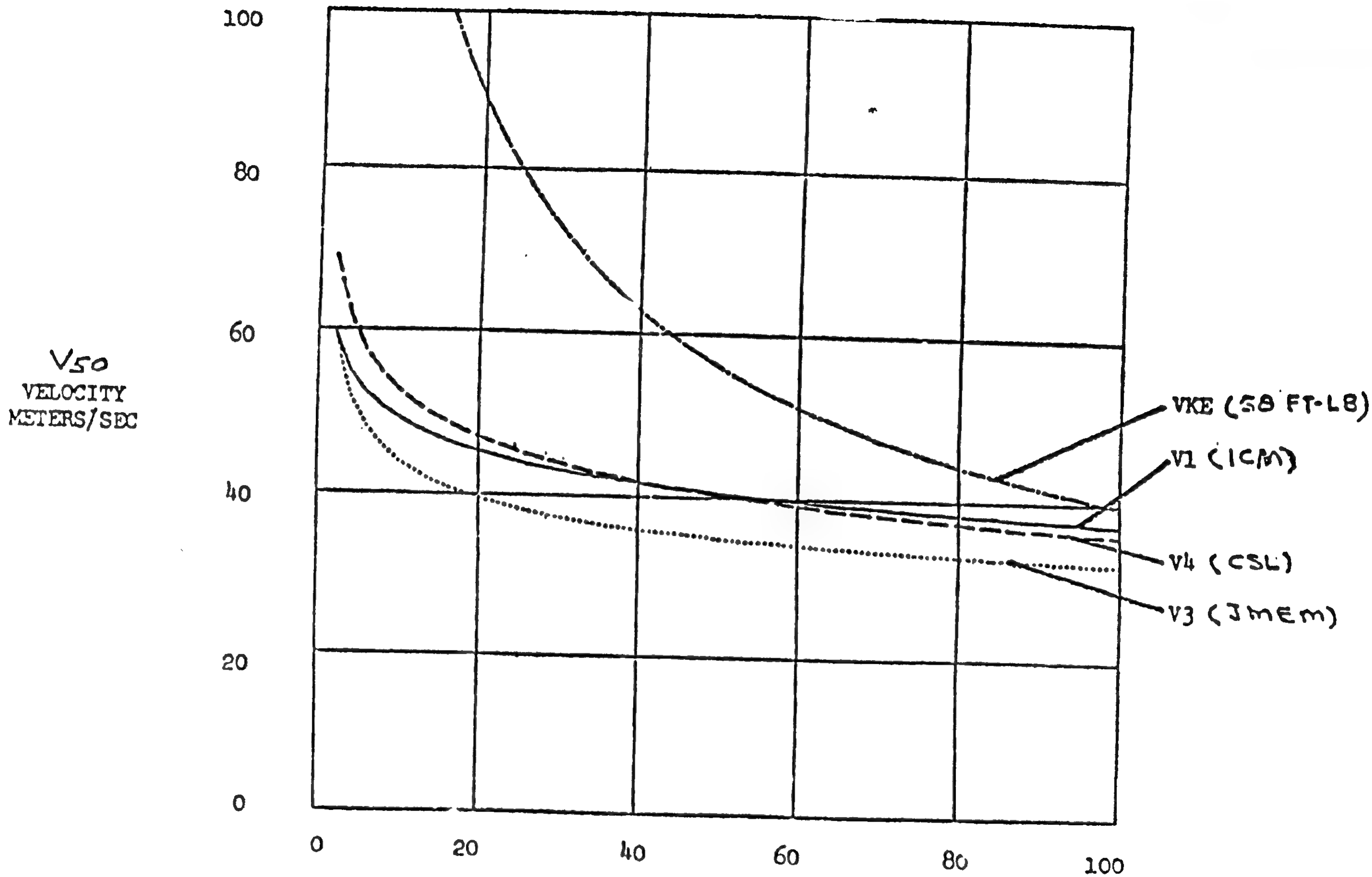


Figure 4. Comparison of fragmentation safety criteria

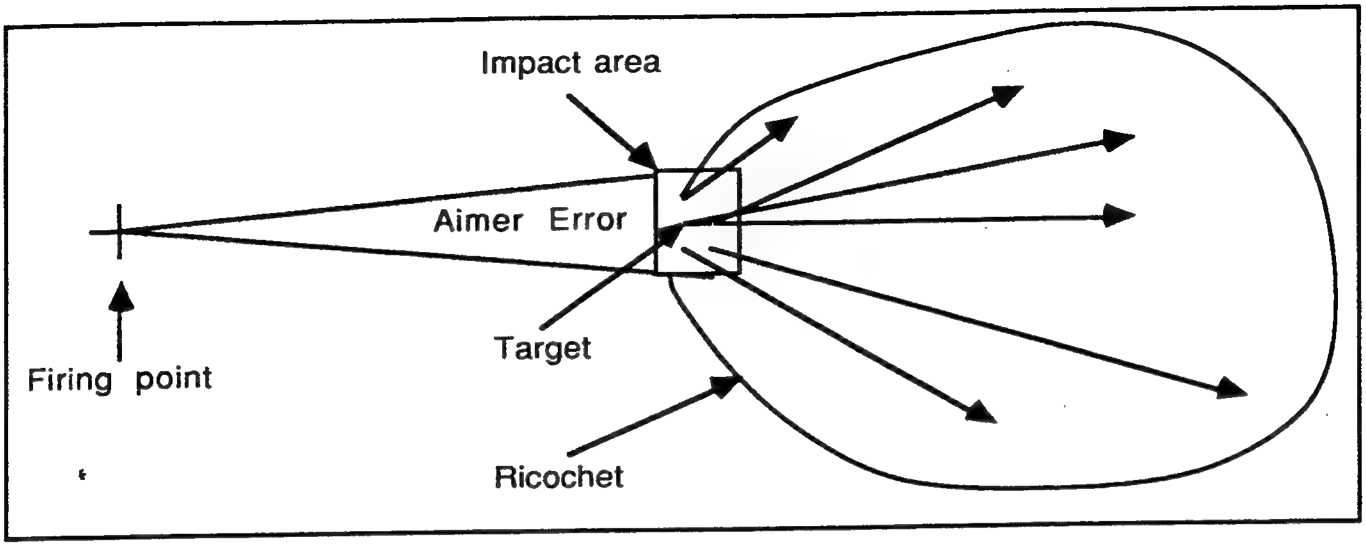


Figure 5. Case 1 - direct fire mode (nonexplosive projectile)

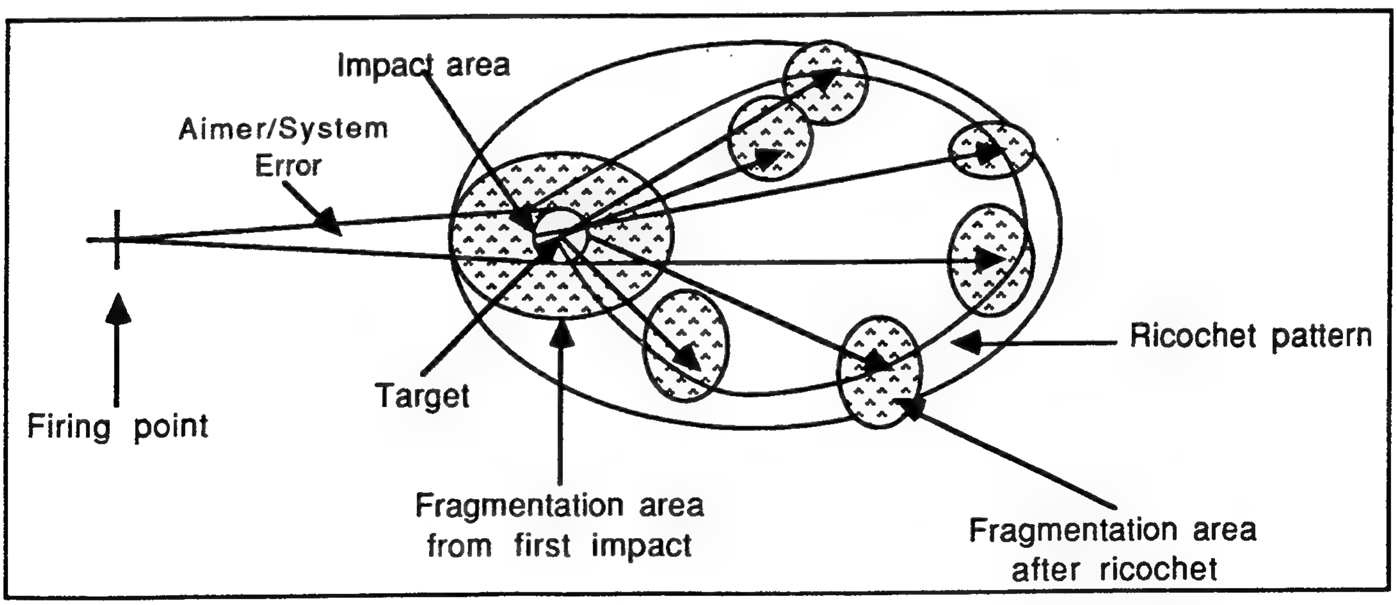


Figure 6. Case 2 and 4 - direct fire mode (explosive projectile)
indirect fire mode (low quadrant elevation)

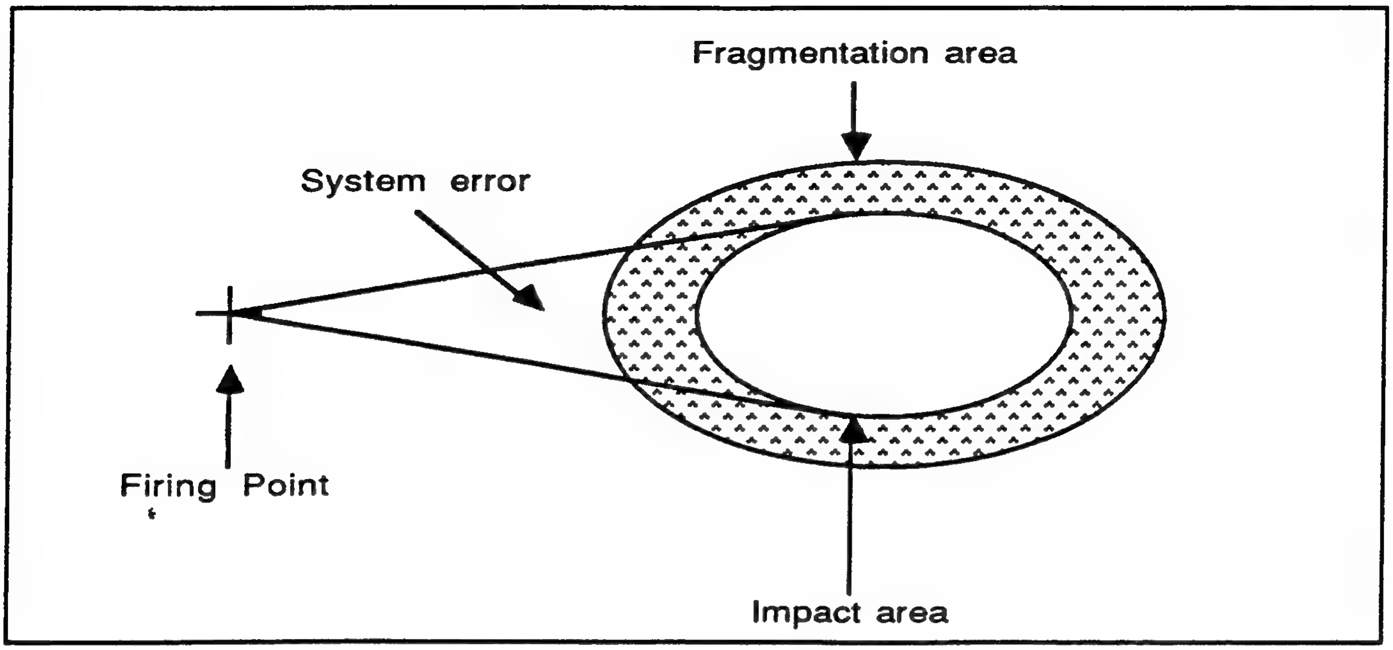


Figure 7. Indirect fire mode

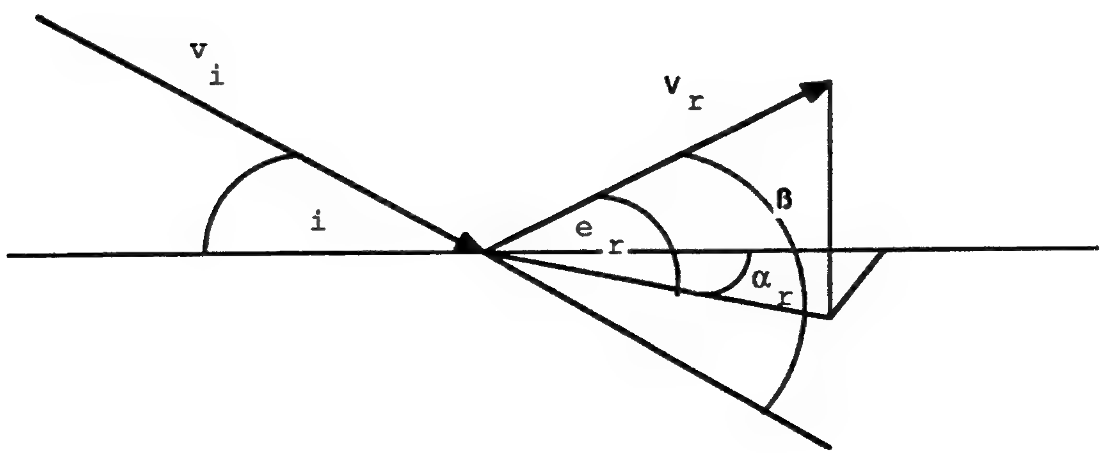


Figure 8. Ricochet diagram

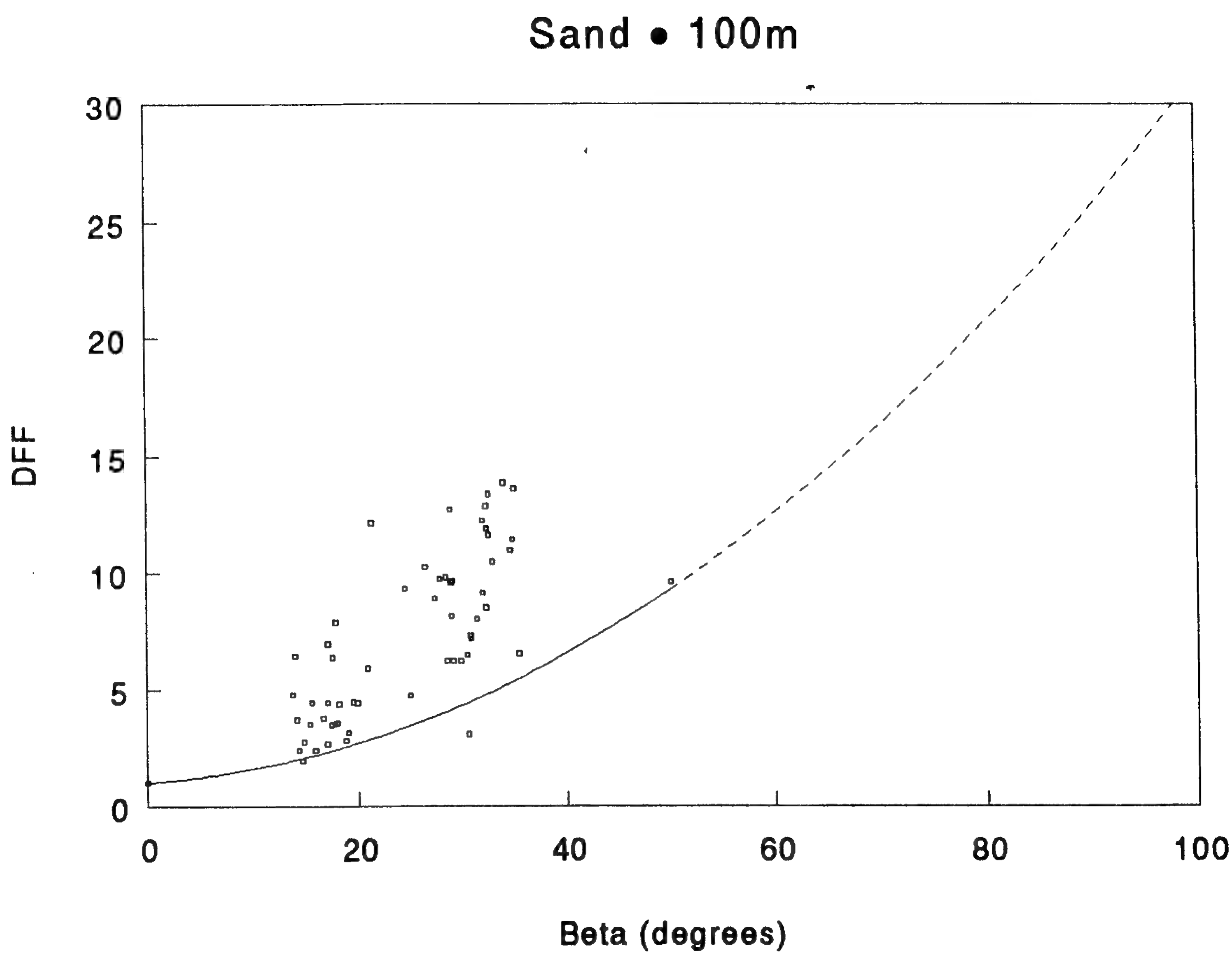


Figure 9. Drag reduction analysis (.50-caliber Ball)

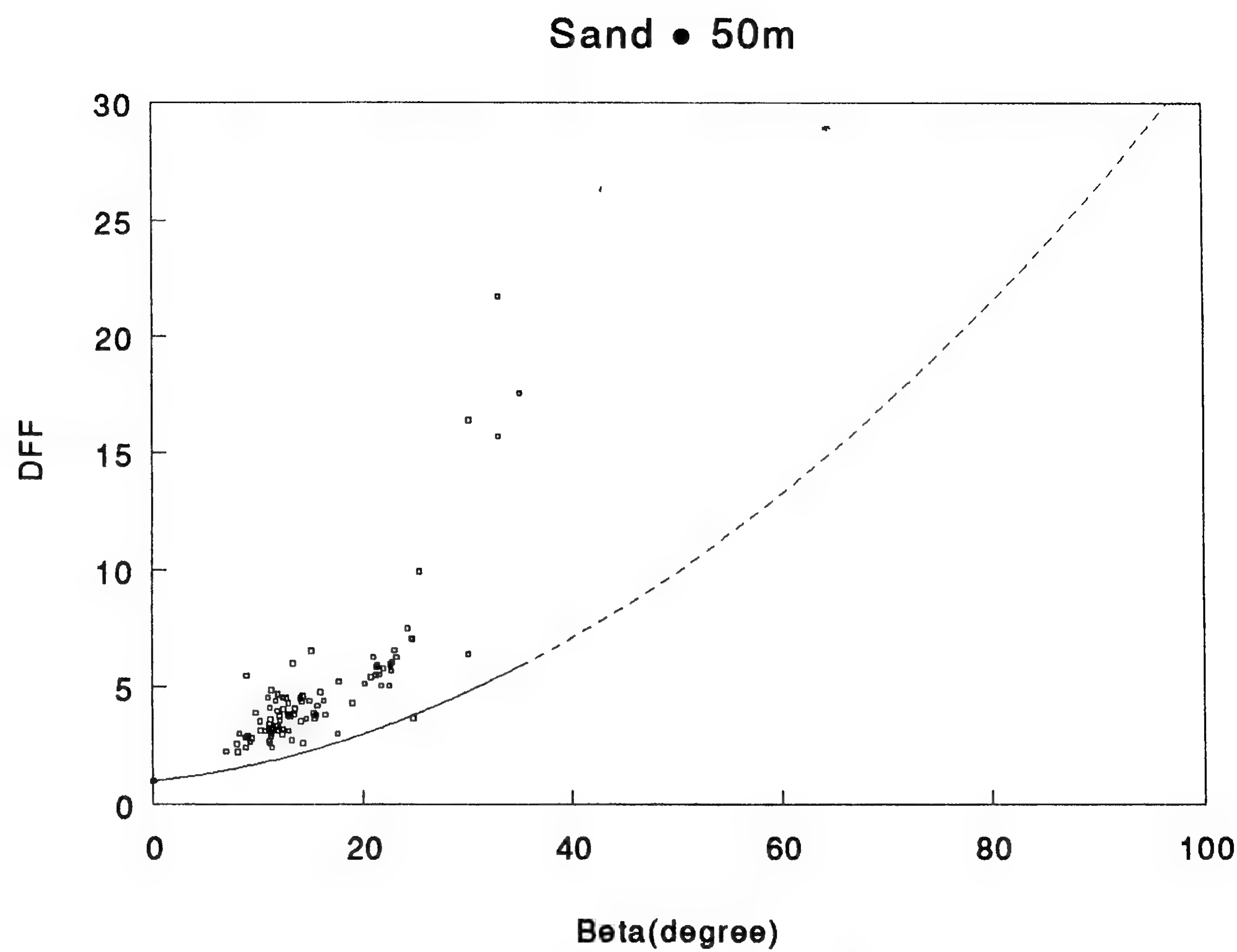


Figure 10. Drag reduction analysis (9-mm Ball)

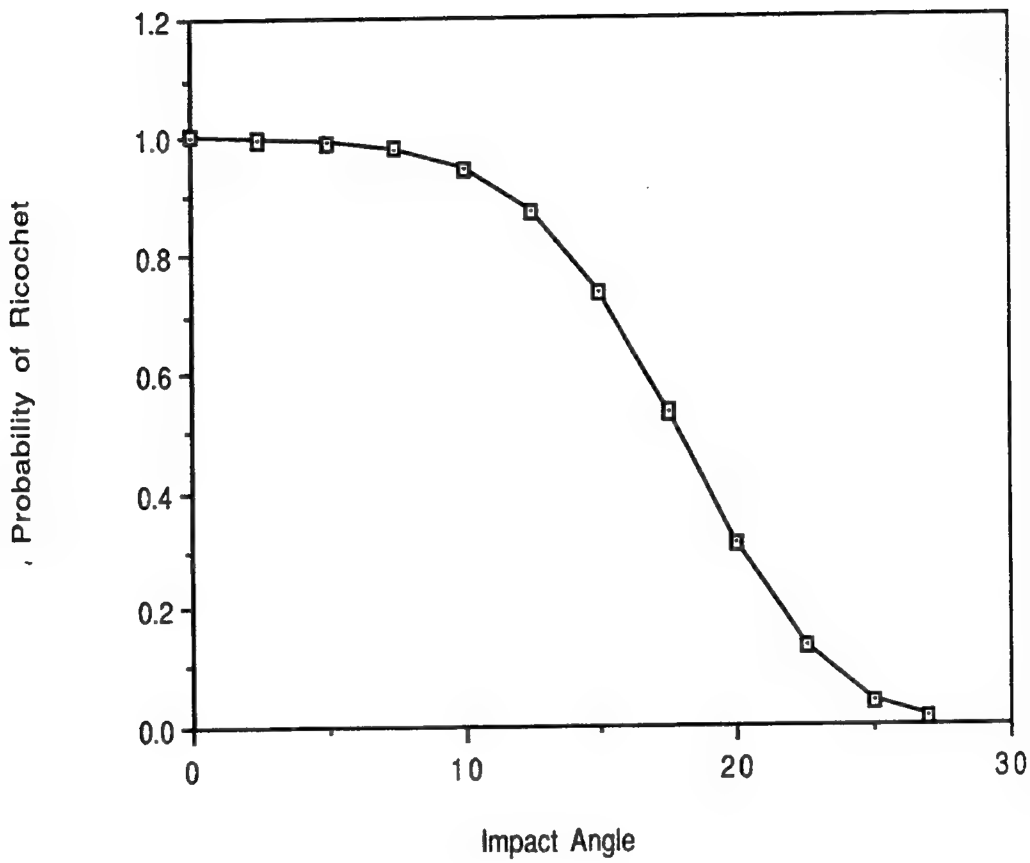


Figure 11. Ricochet probability versus impact angle
M33, .50-caliber - sand

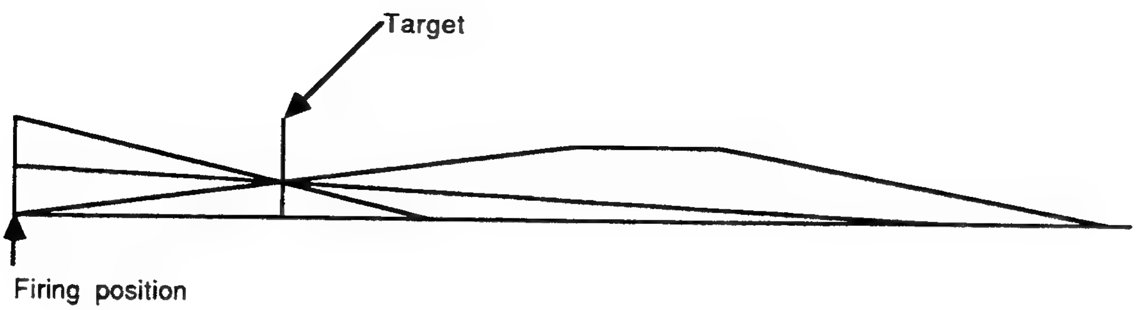


Figure 12. Firing position affects on SDZs

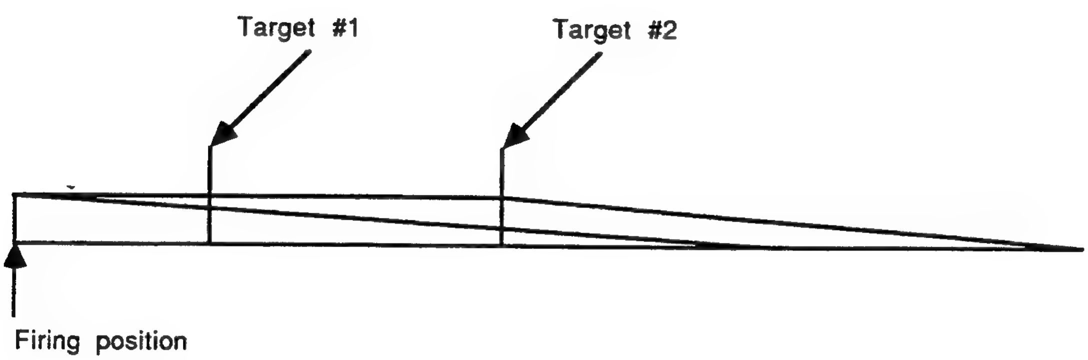


Figure 13. Target location affects on SDZs

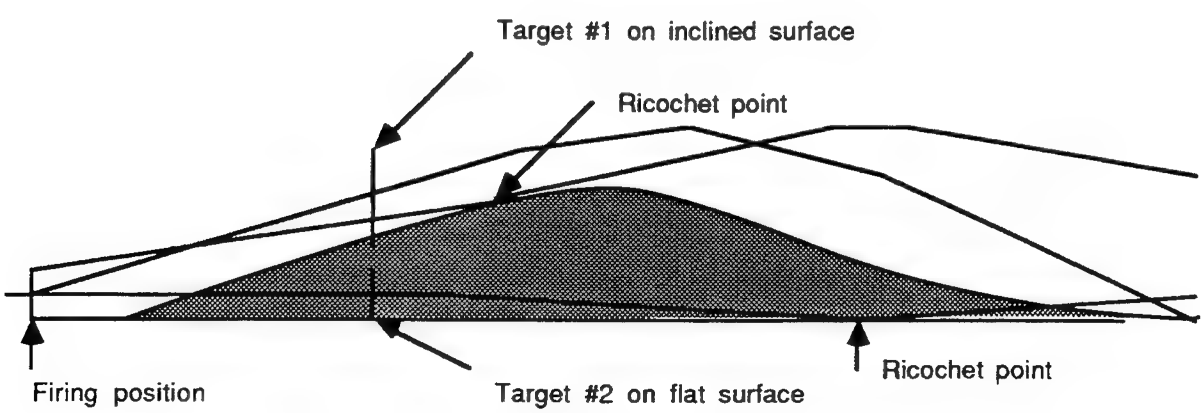


Figure 14. Terrain affects on SDZs

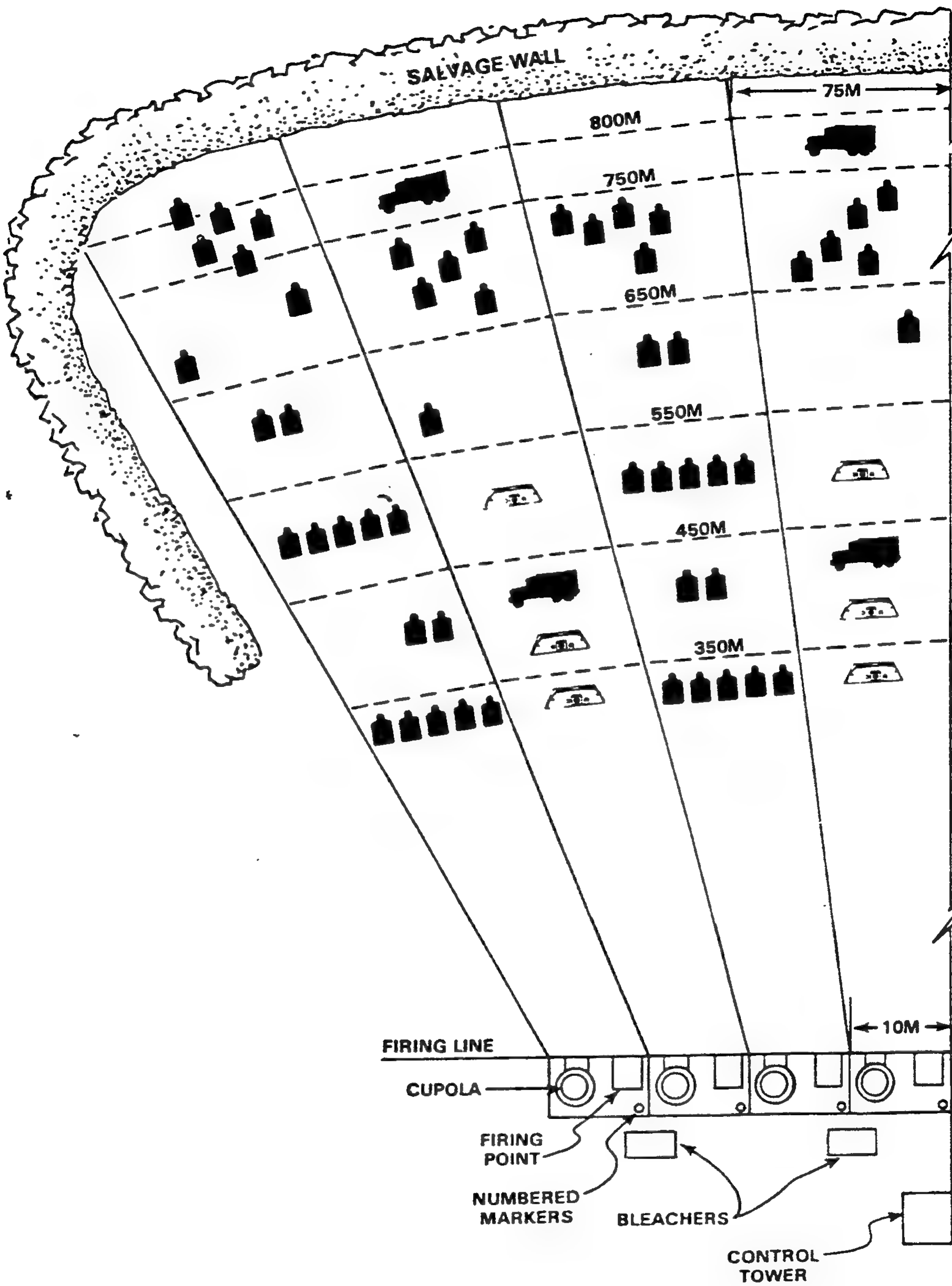


Figure 15. .50-caliber machine gun field firing range

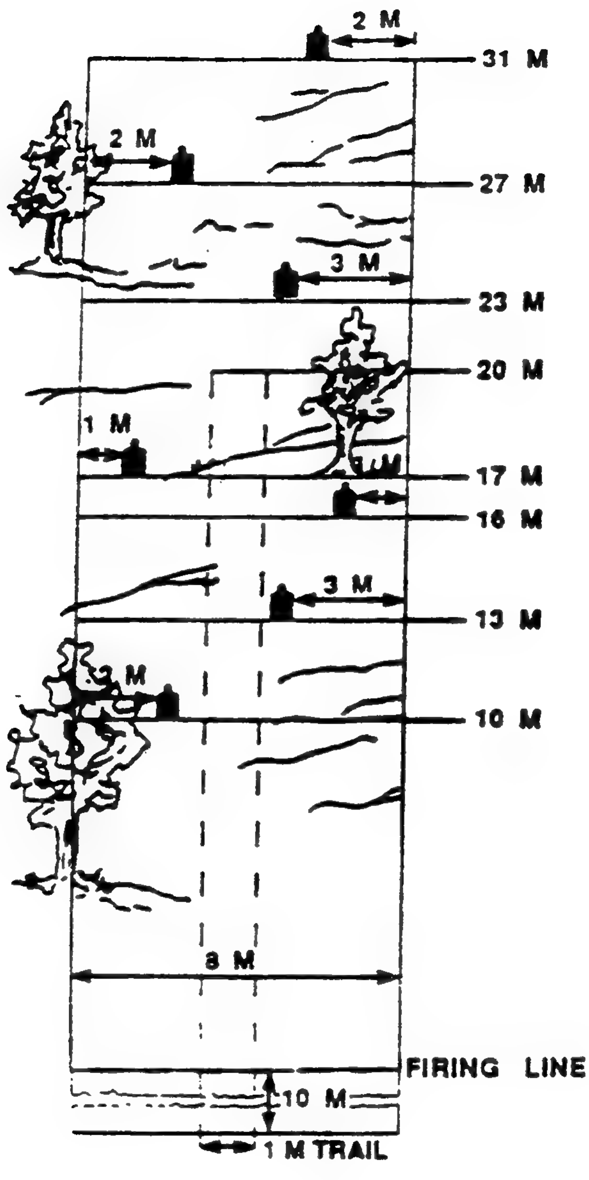


Figure 16. Combat pistol qualification course (CPQC)

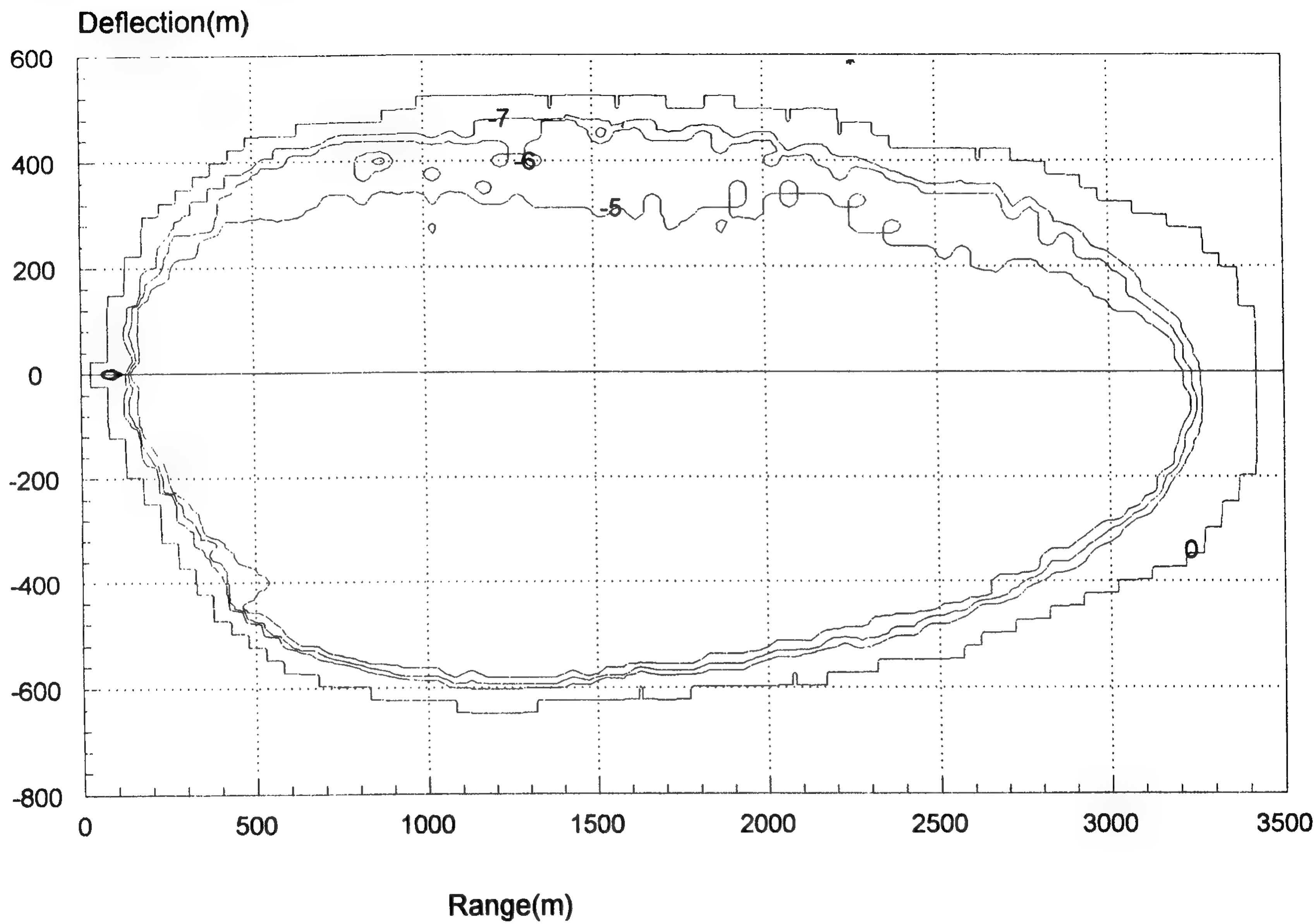


Figure 17. SDZ for .50-caliber Ball - log of probability contours
(impact media: sand with target at 300 m)

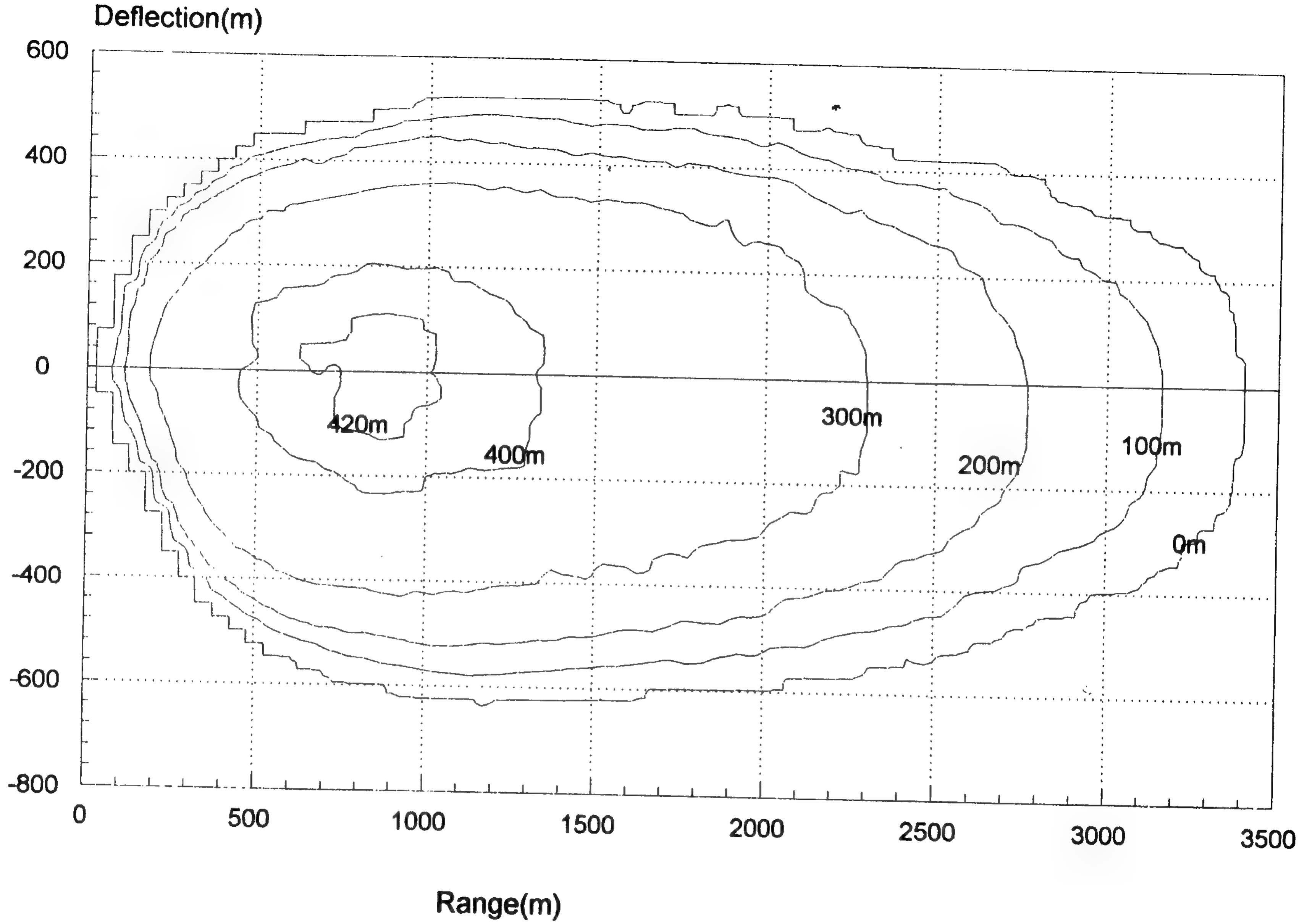


Figure 18. SDZ for .50-caliber Ball - altitude contours for zero probability (impact media: sand with target at 300 m)

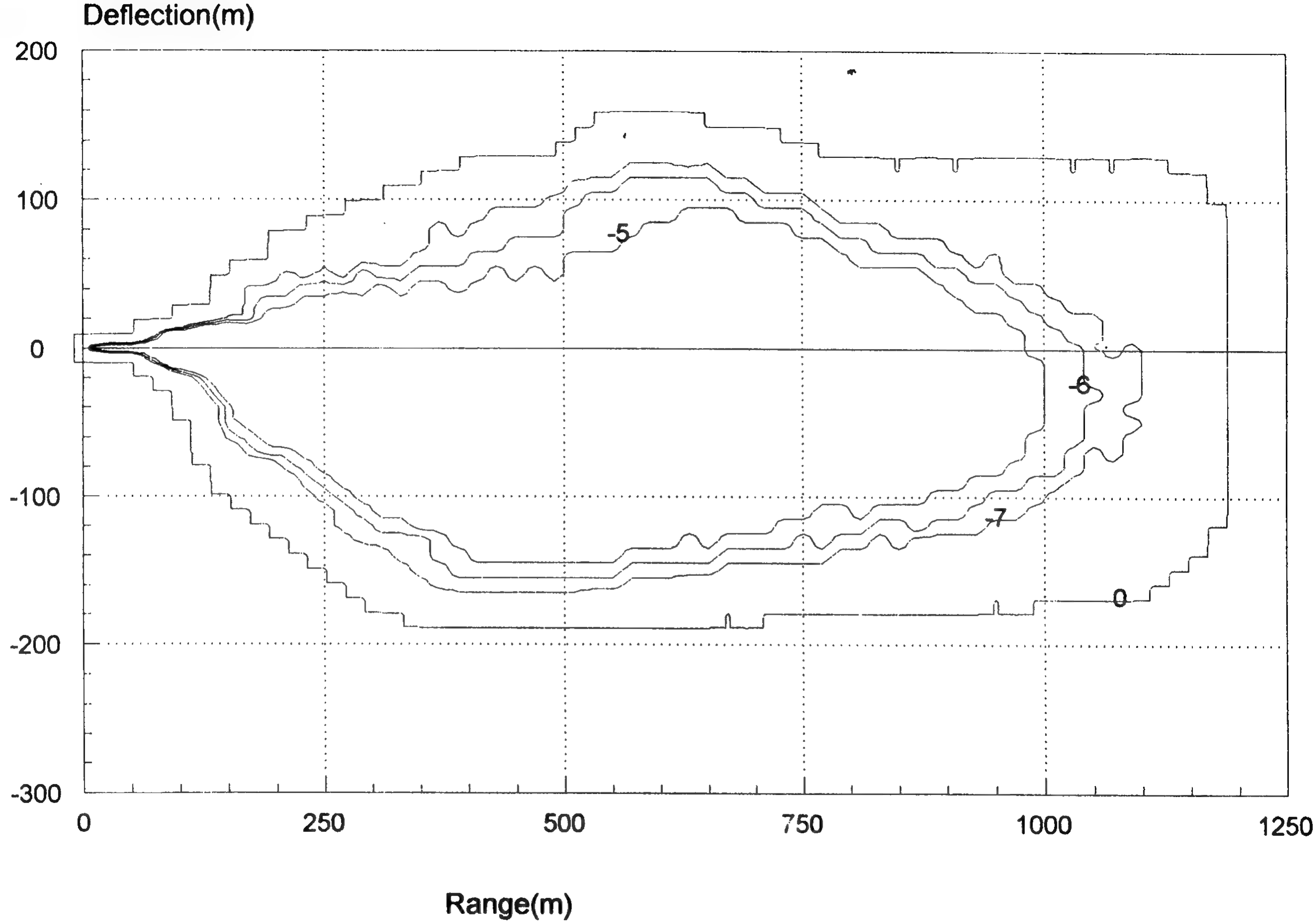


Figure 19. SDZ for 9-mm Ball - log of probability contours
(impact media: sand with target at 25 m)

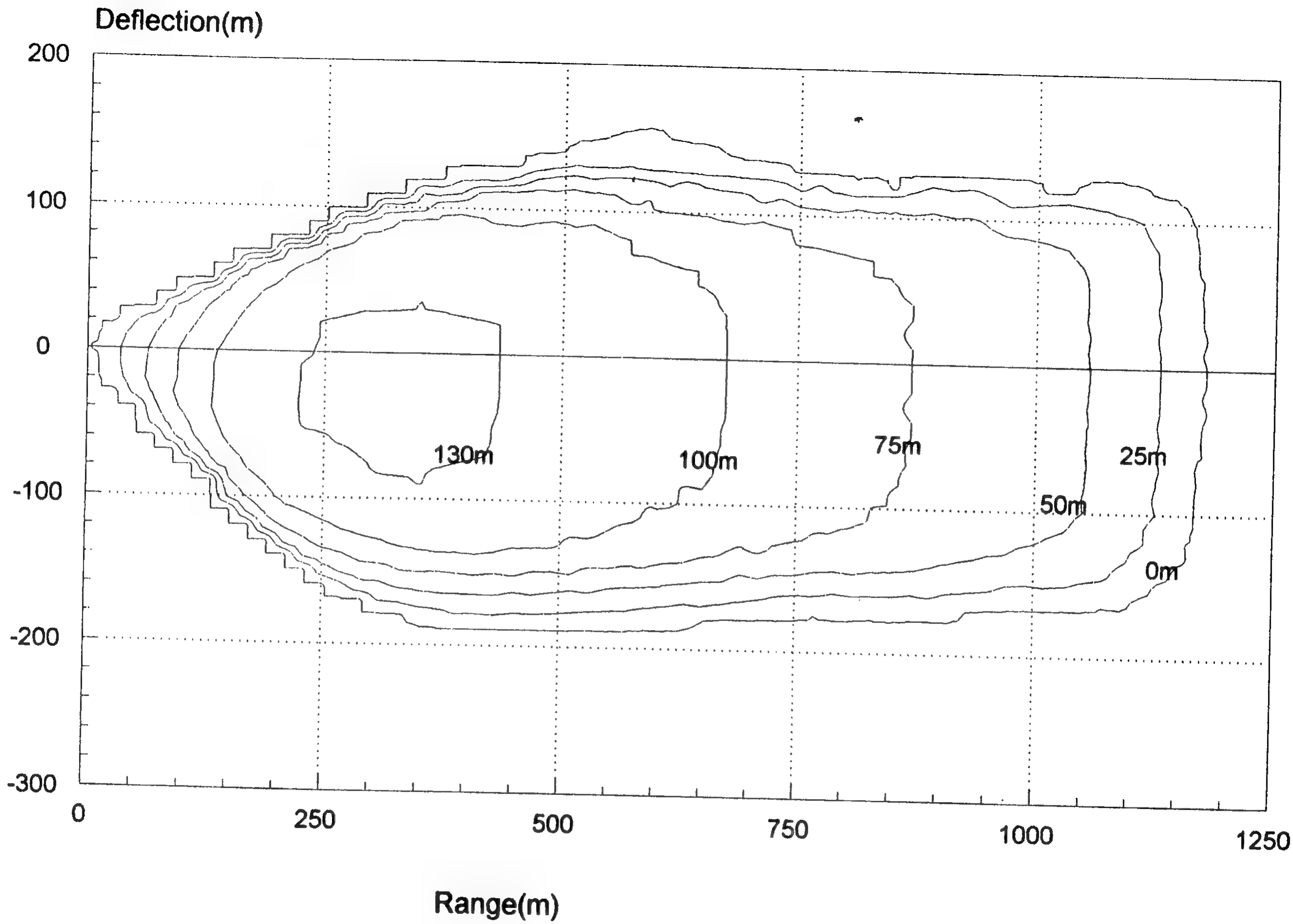
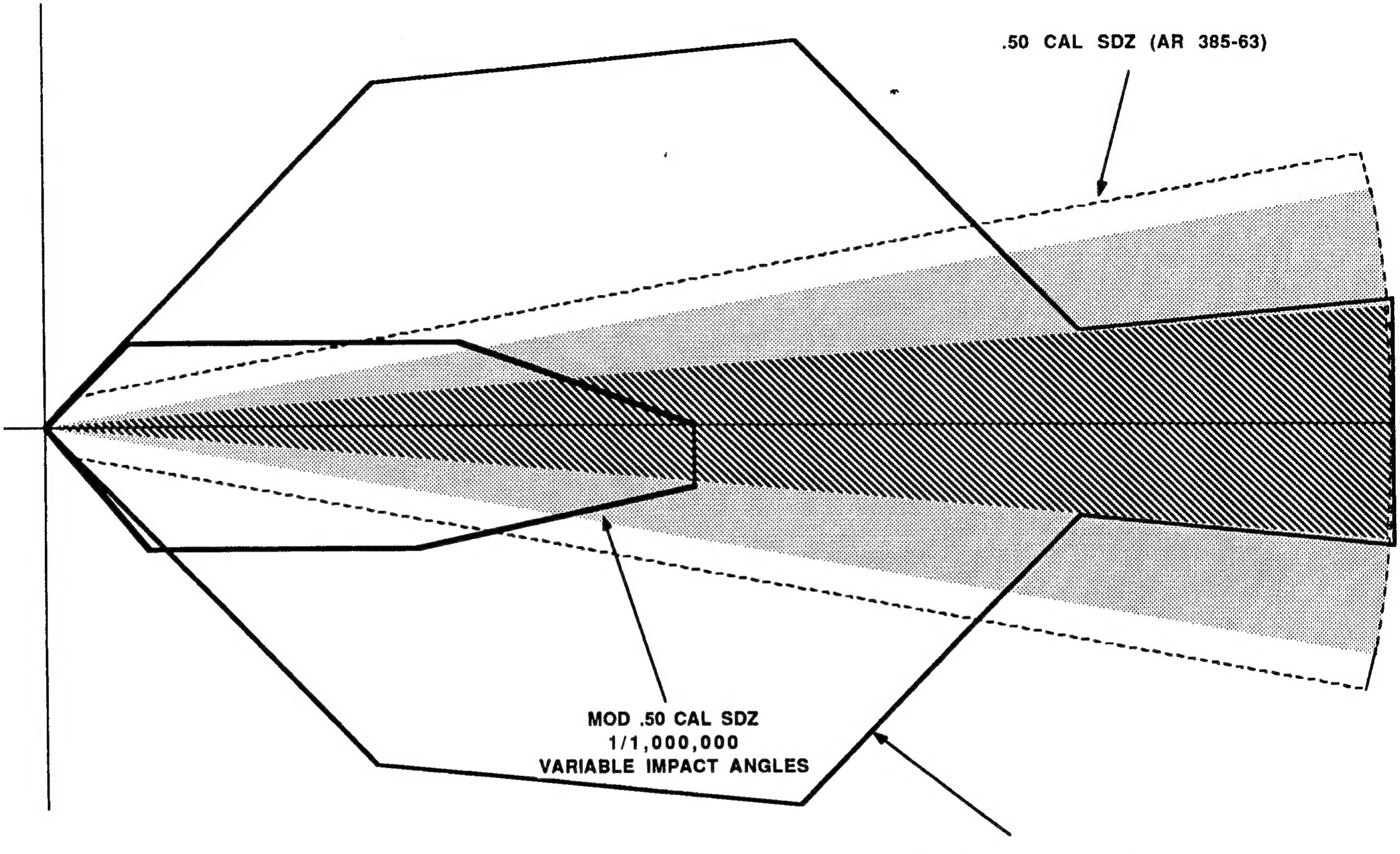


Figure 20. SDZ for 9-mm Ball - altitude contours for zero probability
(impact media: sand with target at 25 m)



Terrain is assumed flat and composed of sand, earth, or similar type material.

Figure 21. .50-caliber SDZ comparison of different methodologies

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